A 50KW PFC THREE-PHASE RECTIFIER FOR USING IN A PLASMA TORCH SYSTEM

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***Abstract* – This essay describes a rectifier structure AC/DC shaped in a 3Ø- phase stage of IGBTs boost, with a pre-regulator of load for a power factor correction. Clark and Park transformations were used to control the system. A TMS320F2812 DSP was used to accomplish the control.**

***Keywords* – DC bus regulator, DSP, power factor correction (PFC), space vector modulation (SVM).**

I. INTRODUCTION

The low power factor checked in the input of rectifiers unities is a problem that have been researched for a long time due to the growing need of improvement and better ratio use of electricity.

For a long time the main cause of the low power factor in industrial facilities was the big number of rotative electric machines used. Due to its major inductive features, the power factor of these facilities that used to make use of electric machines was directly affected by its displacement factor. This problem used to be suddenly solved by inserting capacitors in the utility line.

All about this context arises the need to correct this power factor in a real time situation, using techniques of active correction that are able to adapt itself for each load situation. Besides, it tries to reduce harmonic contents injected by the several non-linear loads, also reducing the distorted factor of the current drained by these loads. For that, the space vector control of current with space modular system consists to check out the flow access in the converter and control it through a high frequency switch exchange just to make it follow a sinusoidal reference generated from the input voltage of converter. It is a very useful compensation technique for converters that are an input current source, just like it is, in fact, the boost converter and some other topological kinds of converters[1][2][3].

As presented, this essay focuses to show as a project a computer simulation and details about an experimental development of control in the DSP TMS320F2812 directed to the 3Ø-phase SVM PFC, which will be a stage of a residues treatment plant that use thermal plasma techniques to treat industrial refused.

II. PRELIMINARY CONSIDERATIONS TO THE RECTIFIER CONTROL

A. Reference Frame Transformations

It is assumed that the source is a balanced, sinusoidal three-phase voltage supply with angular frequency. It is convenient for this analysis to take the phases angles as follow:

$$\begin{aligned} V_1 &= V\cdot\cos\omega t \\ V_2 &= V\cdot\cos(\omega t-2\pi/3) \\ V_3 &= V\cdot\cos(\omega t+4\pi/3) \end{aligned} \tag{1}$$

Where:

V - Maximum phase voltage
ω - Angular frequency
V_{123} - Input voltages.

The voltage equations in the stationary V_{123} are:

$$\begin{aligned} V_1 &= L\frac{di1}{dt}+va \\ V_2 &= L\frac{di2}{dt}+vb \\ V_3 &= L\frac{di3}{dt}+vc \end{aligned} \tag{2}$$

Where:

i_{123} - Input currents.
v_{abc} - Input voltages of the synchronous rectifier;
L - Interface inductor.

B. Clark Transformation

Clark transformation converts balanced three-phase quantities into balanced two-phase orthogonal quantities.

The Clark's transformation matrix is given by:

$$\begin{bmatrix} v\alpha \\ v\beta \end{bmatrix} = \begin{bmatrix} 0.8165 & -0.4082 & -0.4082 \\ 0 & 0.7071 & 0.7071 \end{bmatrix} \cdot \begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix} \qquad (3)$$

C. Park Transformation

The Park Transformation can be seen as the result of the combination of the Clark transform combined with a rotation over an angle.

The Park's transformation matrix is given by:

$$\begin{bmatrix} vd \\ vq \end{bmatrix} = \begin{bmatrix} \cos(\omega t) & \sin(\omega t) \\ -\sin(\omega t) & \cos(\omega t) \end{bmatrix} \cdot \begin{bmatrix} v\alpha \\ v\beta \end{bmatrix} \qquad (4)$$

A rotating vector in αβ space can be a constant vector in a rotating space.

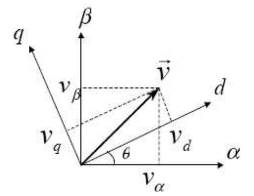

Fig.1. Coordinate transformation of line voltage from fixed αβ coordinates to rotating d-q

D. Inverse Park Transformation

It converts rotating reference frame vectors to two-phase stationary reference frame.

Where the transformation matrix is given by:

$$\begin{bmatrix} v\alpha \\ v\beta \end{bmatrix} = \begin{bmatrix} \cos(\omega t) & -\sin(\omega t) \\ \sin(\omega t) & \cos(\omega t) \end{bmatrix} \cdot \begin{bmatrix} vd \\ vq \end{bmatrix} \qquad (5)$$

E. Current Control

The control circuit is based on the instantaneous active and reactive currents id-iq method [4].

The instantaneous active (id) and reactive (iq) current components are obtained from the converter AC currents in αβ .

In order to obtain unity power factor, it is desired that reference frame current iq be zero. [5][6]

Where the transformation matrix is given by:

$$\begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} = \begin{bmatrix} 0.8165 & -0.4082 & -0.4082 \\ 0 & 0.7071 & 0.7071 \end{bmatrix} \cdot \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} \qquad (6)$$

The rotation over an angle ωt is done according to the formulas:

$$\begin{bmatrix} id \\ iq \end{bmatrix} = \begin{bmatrix} \cos(\omega t) & \sin(\omega t) \\ -\sin(\omega t) & \cos(\omega t) \end{bmatrix} \cdot \begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} \qquad (7)$$

The reference frame current id is obtained from the DC voltage controller.

The DC link voltage controller is adopted in the outer control loop to regulate the DC bus voltage [7][8][9].

From this linearization, a PI controller is designed to reduce steady state error.

The angle ωt is determined by $v\alpha\beta$ voltages.

Where:

$$\omega t = \theta = \tan^{-1}\left(\frac{v\beta}{v\alpha}\right) \qquad (8)$$

DSP is written:

Computation of atan2 based on look-up atan table:

```
void main(void )
{
xin1=_IQ(vα)
yin1=_IQ(vβ)
angle=_IQatan2(yin1,xin1);                    (9)
}
```

F. Realization of Space Vector PWM

Space vector modulation (SVM) is based on the representation of the three-phase quantities as vectors in a two-dimensional (αβ) plane. This technique reduces through a switch configuration assuming binary values, 0 or 1.

The space vector is realized based on determination $v\alpha$, $v\beta$, on duration T_1, T_2, T_3, which represent the times widths for vectors V_1, V_2, V_0, T_0 , where T_0 is the sampling period for null vectors.

The possibility to minimize the output signals harmonic contents and the use of higher levels of modulation are the main advantages of this technique.

There are eight possible switch combinations with the obtention of space vector module procedure. Two of these possibilities result in null vectors (equal zero), the remaining six vectors have module equal to $\sqrt{2/3}$ [10][11][12].

G. DSP Implementation

The DSP implementation diagram of the proposed digital PFC control method is shown in Fig. 2. The output voltage is sensed and feedback to the DSP via ADC module.

The output feedback voltage signal is compared with the reference voltage and the difference produces the error signal for the voltage regulator.

The output voltage regulator establishes the amplitude of the reference current. The input voltage is sensed and processed by atan2 based on look-up table. [13][14][15][16].

The gate signal is established by the duty cycle calculation and provided for the switch by the PWM module of DSP.

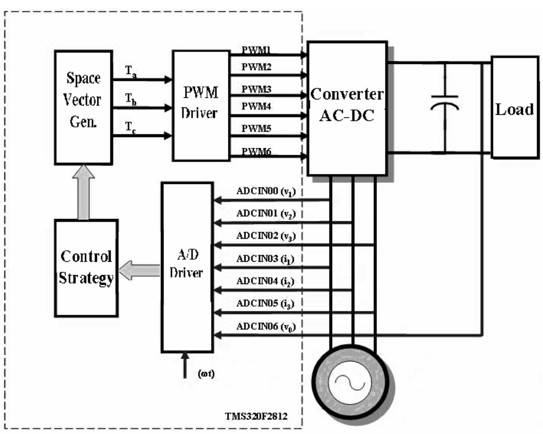

Fig. 2. DSP controlled PFC implementation.

H. Converter Topology

The circuit of the converter is very well-known in the electrical engineering literature, and can be observed on Figure 3. The IGBTs modules of Semikron SKM150GB128D have been detailed for an AC-DC converter, to be arranged two by two in each stage. The Semikron rectifier already contains in it the power source structure, IGBTs start drivers, capacitors of DC bus, the heatsink and the ventilation fans used in it. Besides this structure, there are three inductors.

The pre-regulator of load is used to optimize the power factor providing a DC voltage controlled from a line power source stored by electric grid system of local power plant, correcting this way the power factor of all system. This DC voltage level at the output bus may vary between the minimum of 600VDC to the maximum value of 850VDC, with a max 75A electric. The output voltage adjustment, impressed in the DC bus powered by the group of alteration switches consists in another subject, theme of another projects developed by some members of this same work.

This 3Ø-phase PWM boost rectifier uses space vector modulation techniques to synthesize the current lines and improves the power factor correction (PFC). It is necessary the use of a pre-regulator power factor, in the access first step, due to the presence of strong reactive compounds introduced by the inductive load of the torch.

The power required to the plasma torch, in normal regular operation conditions, must be around 50 kW.

The switch system will be executed following a soft commutation pattern, to minimize all the damages produced in the IGBTs, utilizing the ZCS [15][17], in 20 kHz frequency.

The command generation for IGBTs and process strategy is done by a DSP TMS320F2812 EZDSP module from Texas Instruments. Additionally, the DSP module will develop several functions required by the rectifier, as well as, will check out some operation parameters. The interconnection between the DSP module and the drivers will be made using fibers optics, just to eliminate possible EMI interferences.

The DSP will achieve the control algorithm, A/D and D/A conversions. The space vector communicates with the user through a serial port RS-232 available in eZdsp™. Due to the digital flexibility of controller this converter can be configured as a rectifier or an inverter, soft switched or not, in a quick way[14].

There is an interface board that acts as an adapter between DSPs PWM pulses and the optic signals which are directed to drivers, besides it collects the signals failures from these drivers.

This structure can effectively make the controller less liable against noise effects. Another potential benefit of using optic fibers is to minimize the number of wires between the controller and the power stage system.

The output and input voltages will be sense by using a 4N25 opto-coupler and current measure will be accomplished by using a Hall Effect sensor which achieves galvanic isolation between the control and power circuits.

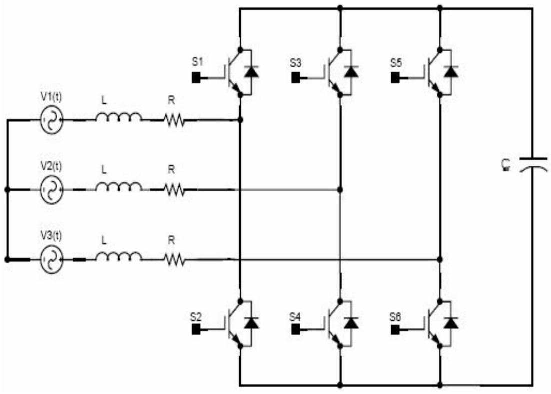

Fig. 3. Three-phase

I. Converter Specification

The topology adopted for the AC/DC converter showed in this project is the result of a very selective process for a scientific definition. During this process a previous study was done for the rectifier, the load pre-regulator and the pulse static switches.

TABLE I
Specifications

Inputs	
Phase to phase voltage	380VAC ±15% 3Ø
Phase to neutral line voltage	220VAC±15%
Supply frequency	60Hz ±5%
Maximum input power	60kW
Power factor	≥0,95
Harmonic distortion	≤5%
Outputs	
DC link voltage	$550V_{DC}$ a $850V_{DC}$
Switching frequency	25kHz
Output undulation voltage @ 60kW	≤5
Output regulation voltage @ 60kW	≤5%
Power factor control	Independent, at 3Ø- phase

III. HARMONIC AND CURRENT STANDARDS

In a generic way, the harmonic elements sensitivity and endurance grade depends on, in its majority, the nature of the connected loads of this system [18][19].

In high level power systems, the harmonic contents assumes serious dangers. The low frequency harmonics current injection in the electric system line is another challenge to be which cause system efficiency reduction and power losses elevation rate. Hence, it is necessary to respect the harmonic distortion limits established on the norms and others standard regulations, otherwise or these systems may corrupt or pollute the electric system line and harm or damage other users connected to it [20].

IV. CONTROL SIMULATION

From this preliminary and theoric study was conceived a structural project to be developed in laboratory, properly evaluated via digital numerical simulations using *Borland C++ version 5.02 and Matlab® version 7*.

This simulation provides some results that are an instrument to evaluate the achieved project, as well as they are able to validate the studies and the theory results gathered.

The critic point about the PWM boost rectifier with power factor correction is about the reduction of the commutation losses by space vector modulation, reducing the period of operation of each switch maintained in constant commutation. Using the modulation technique applied in this project, each rectifier circuit section remains in a single operation status (without commutations) during the third part of line functions.

In the Figure 4 we it can see input current waveforms.

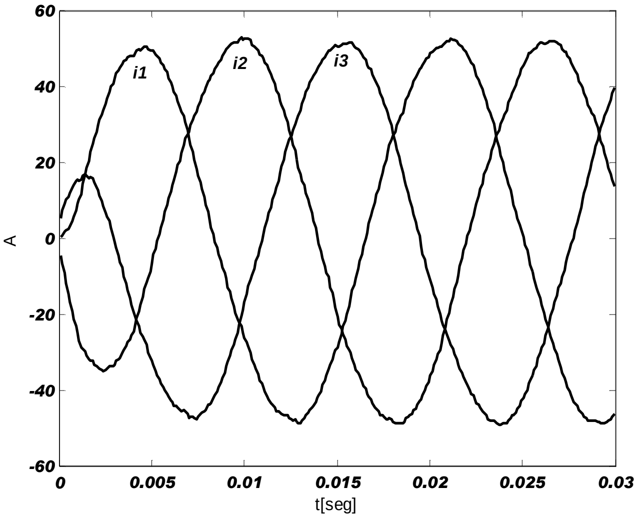

Fig.4. Phase currents.

As it can see in this picture, the input current is sinusoidal waveform, reaching the objective, which is to obtained at the input in a high power factor rate.

Figures 5 and 6 show the voltage of each input phase and the DC bus voltage.

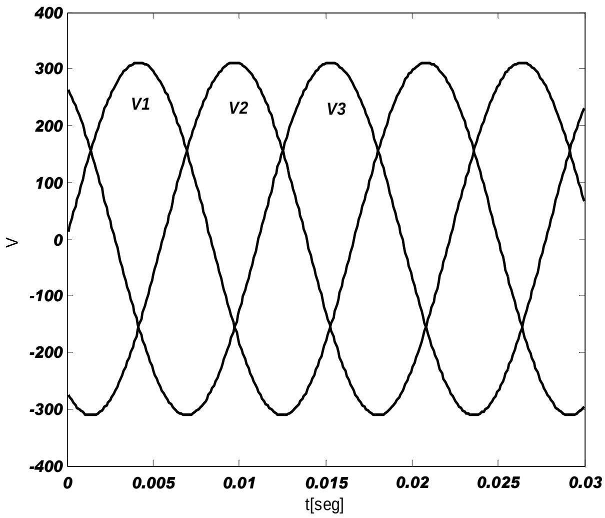

Fig.5. Input voltages.

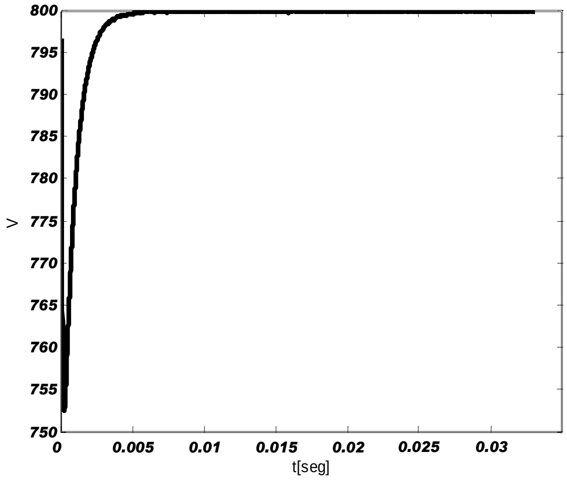

Fig.6. DC link control.

In the Figure 7 it can see the current waveforms and the input voltage. Note that the current has the same phase that the voltage, which means that it have achieved PFC.

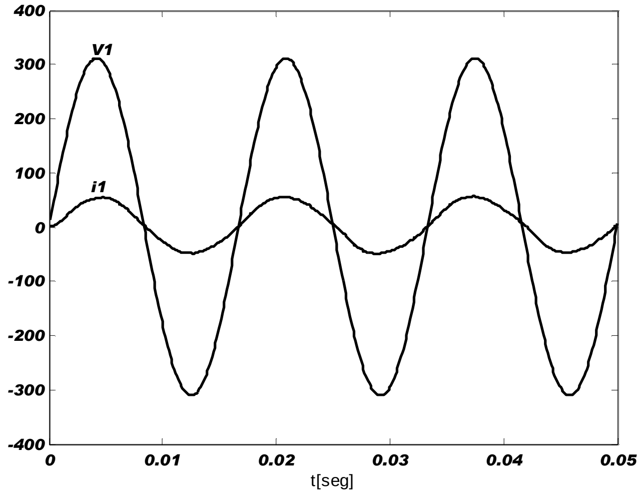

Fig.7. Input current -corrected

V. CONCLUSION

The theoric studies achieved until nowadays point indicate satisfactory results of modular 50kW rectifier operation with power factor correction. The simulations confirm the authenticity of these studies and the accomplished project. The space vector modulation scheme was chosen intending to get minor losses for each keyed switched systems. It will be used soft switching systems with zero current transition whenever the work permit. The reducing question about commutation losses, was the main focus of electronic power team work, was very well done and it is waited good results in next experimental future stages in laboratory.

The simulations were produced by *Borland C++ version 5.02* and *Matlab®* simulations softwares, which was chosen due to they provides important tools, that can be used for power electronics and also it is they are very well-known in the scientific and academic sources.

The DSP implementation diagram of the proposed digital PFC control method is shown in Figure 2. The output voltage is sensed and feedback to the DSP via 10bit A/D converter.

The use of a DSP microcontroller represents a technological attractive solution if considered the involved complexity in the IGBTs command strategy, generation of the command signals and control, as well as the implementation of the several requested functionalities.

It intends in the final version this article presents experimental results and details about the DSP control implementation.

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