Design of a Reversible PFC with Digital Control Using DSP

Julio Cezar Raycik and Marcello Mezaroba
Power Electronics Laboratory – LEPO
State University of Santa Catarina – UDESC
P.O. Box 631, Zip Code 89.223-100, Joinville, SC, Brasil
raycik@joinville.senai.br, mezaroba@joinville.udesc.br

***Abstract* - This work shows a methodology to development of control using a digital processing by DSPs. For the application of this methodology was used a single-phase rectifier with reversibility in current. To this propose was take all the equation applied in this converter by qualitative analysis of variable of voltage and current that are evolved in the process. Is showed the main equations taken. It is also showed the technique of the controller design using this conventional techniques, because the target is to reduce the academic strong ness in the development of research work of new converters using concepts that were already used before and to simplify the knowledge of this process using DSPs, through a using high level programming language which is possible with the use of tools that simplify the code.**

Keywords - DSP Controler, Current Rectifier, Full Brigdh, Retifier, Digital Control.

I. INTRODUCTION

This converter is used frequently in power factor correction that need regeneration of energy that comes of motor brakes, in DC link voltage regulation. Also is used in other application like, active filters, and co-generation.

In this study will be used the method of Mean Value Control used in almost of works, but, the enface is the use of technique of digital control.

II. BLOCK DIAGRAM OF CONTROL USING DSP

The structure of converter studied is showed on figure 1 that is connected to line through an inductor Lin. The side CC is connected to capacitor of filtering Co.

To use a digital controller is necessary to do some addiction in the classic diagram of control, looking to some characteristic of type of control, as showed as Figure 1.

The Anti-aliasing filters are introduced to reduce the components of frequency over the middle frequency of sample. This effect is caused when a signal of high frequency takes the form of a signal with a under frequency.

The circuits of sample and hold are intern circuits in DSP to realize the sample of dates by AD converter.

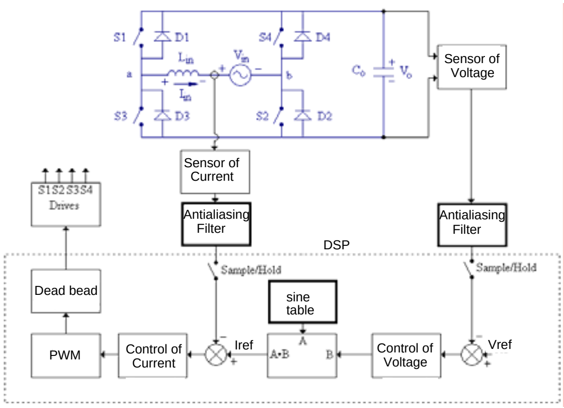

Fig. 1. Diagram of Block of control of Converter.

III. FUNCTION OF TRANSFERENCE OF CONVERTER

A. Function Transference to Current Control

The figure 2 shows the model to big signals to this converter, in function of switching frequency, where the voltage Vin represents the sinoidal voltage input of converter, Lin is the filtering inductor and the output is represented by CC source, where the middle value of this source, depends of voltage on the capacitor Vo and the cyclic ration D as showed on Figure 2.

The function of transference of current Iin in function of D variation, i.e. ΔD, is showed on Eq. 1.

$$\frac{\Delta I_{in}(s)}{\Delta D(s)} = \frac{2 \cdot V_o}{s \cdot L_{in}} \tag{1}$$

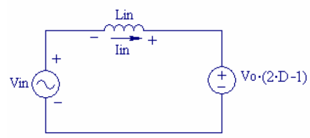

Fig. 2. Model to big signals.

B. Function Transference to Voltage Control

The current produced by the source of current is equal the additon of current of capacitor and resistor at the load, so:

$$(2D-1) \cdot I_{Lin} = C_o \cdot \frac{dV_o}{dt} + \frac{V_o}{R_o} \tag{2}$$

Using Laplace in Eq. 2, come the Eq.3 that represent the function of transference of voltage loop.

$$\frac{V_o(s)}{I_{Lin}(s)} = \frac{R_o \cdot (2D-1)}{1+s\cdot R_o \cdot C_o} \qquad (3)$$

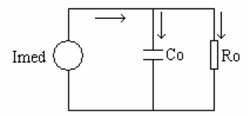

Fig. 3. Simplified circuit of converter to control of voltage.

IV. METHODOLOGY TO PROJECT OF DIGITAL CONTROLLERS

In Ogata [4], is showed some procedures to make a project when digital controller is used.

1. Take G(z) initially, i.e. the transformed **z** of the plant after the sample. Then the bilinear transformed is used to take the function transference to the **w** dominium.

2. Substitute **jω** for **jυ** in **G(jω)** and trace the Bode's diagram to **G(jυ)**.

3. Then, with the diagram, read the static error and gap of the phase and gain.

4. Using a unitary gain to the low frequency to the function of controller in discrete time, **H(w)**, determinate the gain of system that satisfies the constant of static error. Then, using the techniques of project conventional to the systems of control in continuous time, to determine the poles and zeros of function transference of digital controller.

5. Realize the transformed of the transference function of controller **H(w)** to **H(z)** using the inverse bilinear transformation, obtaining the discrete function of transference of controller.

6. Implement the discrete function **H(z)**, using the differences equation, through a computational algorithm.

V. PROCEDURE USED TO PROJECT OF THE DIGITAL CONTROLLER

The requirements to the project are gived by Batshauer [2], Barbi [3] and Tomazelli [1]. The phase changes between 45^o and 90^o, the inclination of the curve of gain to the open system loop should be –20db/decade, null statistic error, the through frequency to gain curve in the open system loop should be four times smaller than the switching frequency, and the switching frequency should be 10 times smaller than the sample frequency.

VI. DESIGN OF CURRENT CONTROLLER

A. Analyze of Frequency Answer to the FTMAi

$$G_i(w) = K_{PWM}\cdot K_{AD}\cdot K_i \cdot \frac{V_o}{L_{in}} \cdot \frac{1-\frac{Ta}{2}w}{w} \qquad (4)$$

With this function is possible to get some conclusions: 1) It has only one pole in origin, so the static error is null and 2) It is stable, so the inclination at crossover frequency is –20dB/decade;

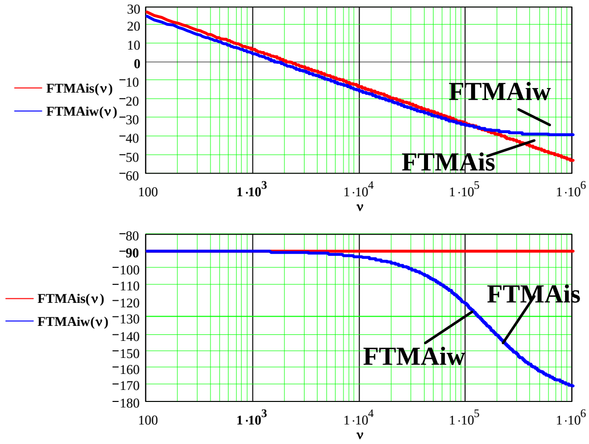

Fig. 4. Frequency answer to plant of current continuous e discrete.

B. Project of Controller of Current

With a gain of FTMA$_i$ without H$_i$(w) is –3,63dB for a frequency of 12,5 kHz, the gain k$_{Hi}$ should be projected to present a gain of 3,63dB, than:

$$H_i(w) = 7{,}46 \qquad (5)$$

C. Analyze of Influence of Controller

To show how the inclusion of the controller H$_i$(w) in FTMA$_i$ affects the answer of system, Bode's Diagram of function of transference is presented in figure on figure 4, together with the answer of the system without controller (G$_i$(w)) and FTMA$_i$ function.

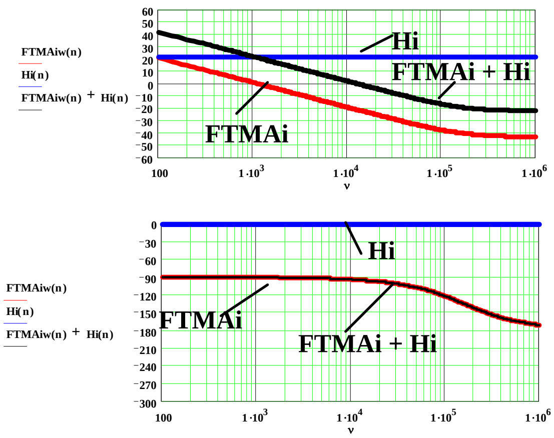

Fig. 5. Answer of FTMA$_i$ with current controller.

D. Inverse Transformed of Controller

With the $H_i(w)$, is possible to reach $H_i(z)$:

$$H_i(z)=7{,}46 \tag{6}$$

E. Difference Equation for Current Controller

Transforming (6) in a difference equation, taking into account the shifting theorem:

$$u_i(n)=7{,}46\cdot e_i(n) \tag{7}$$

VI. DESIGN OF VOLTAGE CONTROLLER

A. Function of Transference to s Plane

The principles of management the design of the voltage loop controller are the same used by management of design of current controller, then one parallel can be traced and the project step can be generalized.

B. Function of Transference to Plane w

$$G_v(w)=A_1\cdot\left(\frac{1-e^{-Ta/A_2}+w.\frac{Ta}{2}\left(e^{-Ta/A_2}-1\right)}{1-e^{-Ta/A_2}+w.\frac{Ta}{2}\left(1+e^{-Ta/A_2}\right)}\right) \tag{8}$$

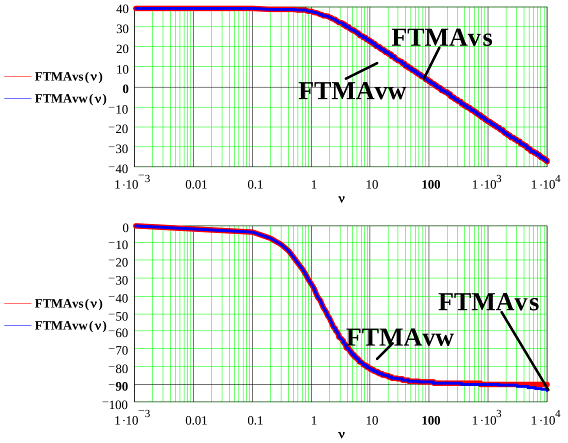

Fig. 6. Frequency answer to plant of voltage continuous e discrete.

C. Function of Transference to Open Loop (FTMAv)

$$\mathrm{FTMA}_v(w)=\mathrm{H}_v(w)\cdot\mathrm{G}_v(w)\cdot\mathrm{k}_v \tag{9}$$

D. Design of Controller Voltage

$$H_v(w)=0{,}0464\cdot\frac{(w+9{,}42)}{w} \tag{10}$$

E. Analyze of Influence of Controller

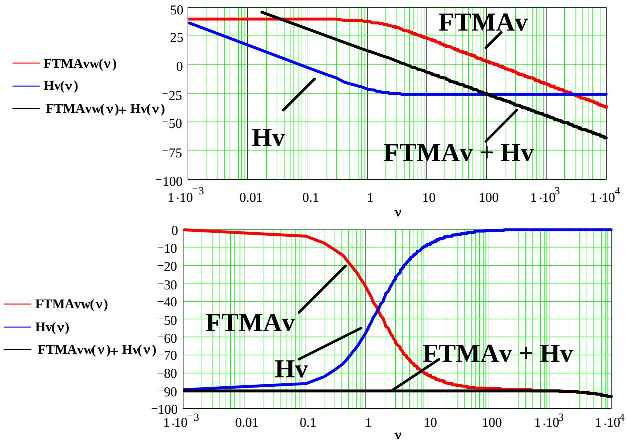

Fig. 7. Answer of $FTMA_i$ with controller of voltage.

F. Inverse Transformer of Controller

$$H_v(z)=\frac{(0{,}0460008671\cdot z-0{,}0459991329)}{z-1} \tag{11}$$

G. Difference Equation for Current's Controller

Translate (11) in a difference equation, account the sampling theorem:

$$u_v(n)=0{,}046\,e_v(n)-0{,}04599e_v(n-1)+u_v(n-1) \tag{12}$$

VI. NUMERIC SIMULATION

To the evaluation of control used at the project is necessary to make some simulation using computing methods to observe the system answers. The software used was the MATLAB, more specifically the SIMULINK, where were used the power system library and discrete blocks to simulate the ADC and calculation made by the DSP.

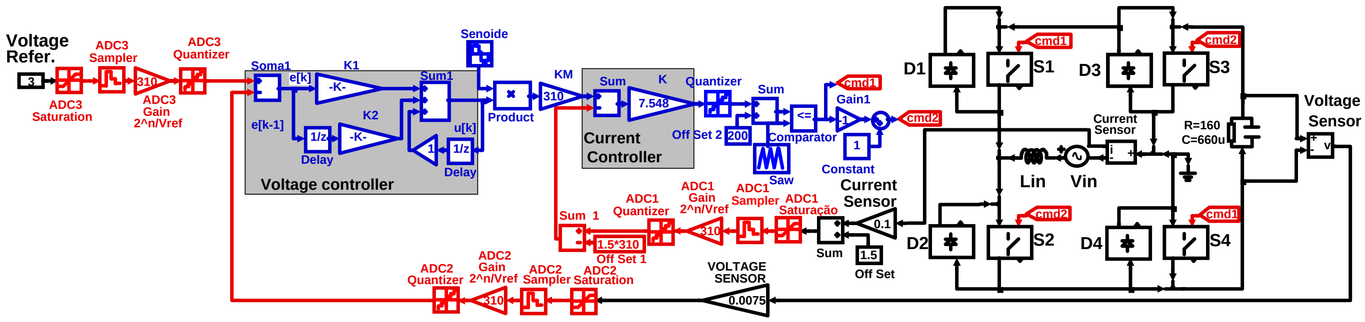

Fig. 8. Block Diagram

A. Simulation Results

The results of simulation are showed here, where is possible observe the input and output current and voltage through the Figures 9, 10, 11 and 12.

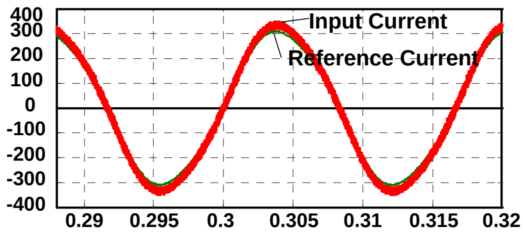

Fig. 9. Reference and Input Current.

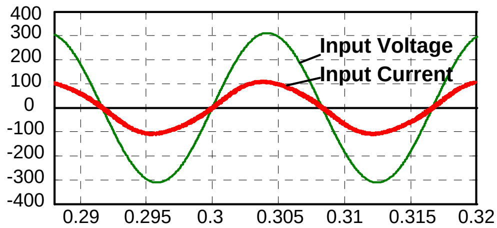

Fig. 10. Input Voltage e Current.

B. Regeneration Mode

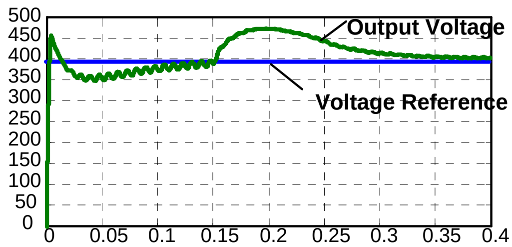

Fig. 11. Output Voltage to Regeneration of Energy.

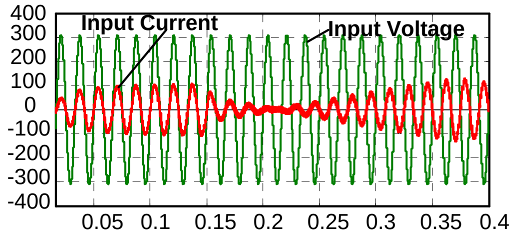

Fig. 12. Regeneration of Energy.

VII. PRACTICAL RESULTS

Following the equations of the mathematical analysis, the information had been concentrated thorough tables.

Thus, the initial design specifications, and the main results can be observed in the *Tables 01* and *02*, respectively.

TABLE I
Initial Design Specifications

Variable Description	Values
Sample Frequency	*fa=500kHz*
Switching Frequency	*fs=-50kHz*
Output Voltage	V_o=400V
Maximum Input Voltage	V_{inpico} = 311V
Current Gain	*Ki=0,0078*
Voltage Gain	*Kv=0,00638*
Output Capacitor	C_o=663,5μF
Output Resistance	R_o = 160
Output Power	P_o = 1kW
Input Inductor	L_{in} = 6mH

TABLE II
Main Components Specifications

Variable Description	Values
S1, S2, S3 and S4	IRGP35B60PD
D1, D2, D3 and D4	Switches intrinsic diodes
Lin	Ferrite Inductor: EE65/39, nfp=19, wires=27AWG, 93 turns, and lg=1,4mm.
Cout	*Electrolytic Capacitor 3x220μF*

A. Change load

In *Figure 13* is presented the waveform take with reduction of load.

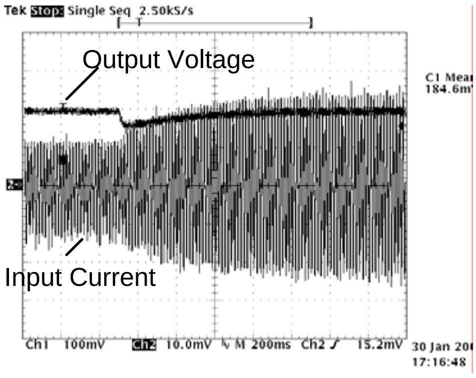

Fig. 13. Change of load (step of 100%).

B. Variation of Input Voltage

In *Figure14* and *15* is showed the test of variation of the input voltage.

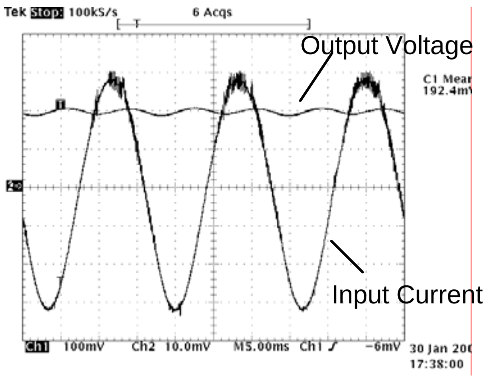

Fig. 14. Reduction of Input Voltage (20%).

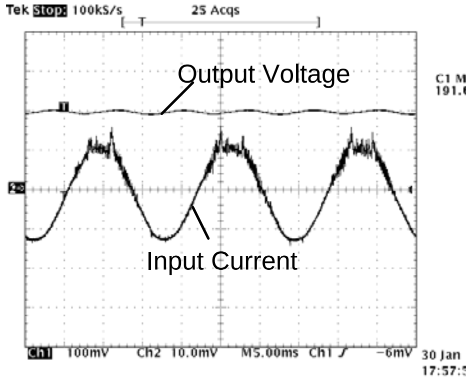

Fig. 15. Step of Input Voltage (step of 20%).

C. Regeneration Mode

The *Figure 16*, *17*, *18* and *19* shows the converter working in regeneration mode.

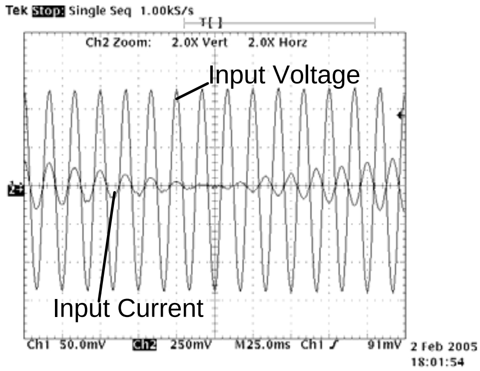

Fig. 16. Working in Energy Regeneration Mode.

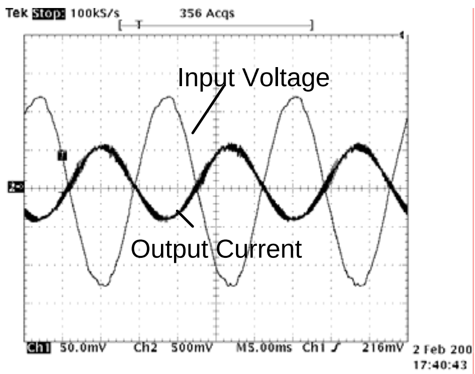

Fig. 17. Working in Inverter Mode.

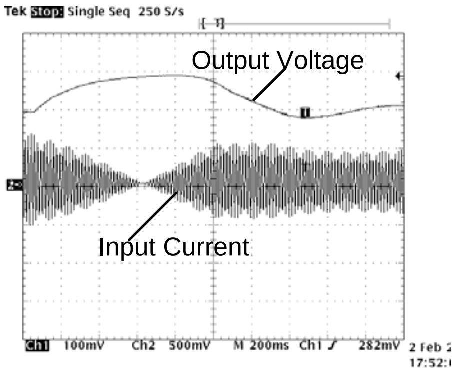

Fig. 18. Though to Regeneration Mode(Inverter).

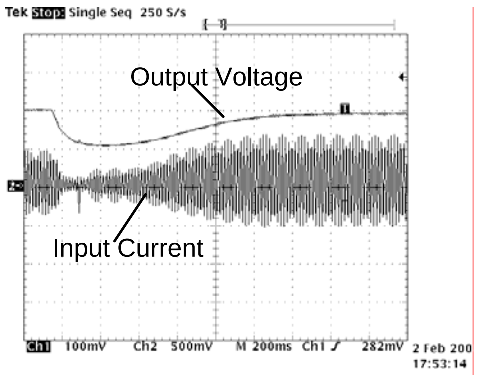

Fig. 19. Come back to Rectifier Mode.

VIII. CONCLUSION

This paper showed a Design of a Reversible PFC with Digital Control Using DSP, this study will be used to implementation of three-phase converter in a future work. Also presented the implementation, and some dates that were taken.

The converter was not tested in the nominal rated power because a limitation of our laboratory equipment. But was possible to observe the efficiency of controller through of the simulation process. Also was observed the simplification of design controller where were used the conventional techniques what can help in the reutilization of project already existent, doing that the fact of using use a digital controller not do add more effort to the project and the study of structure of converter became the main target of research. Lastly it was taken some practical results of implementation where the main result was the functioning in regeneration mode, as obtained in the simulation.

IX. REFERENCES

[1] – TOMASELLI, Luis Cândido; Controle de um pré-regulador com alto fator de potência utilizando o controlador DSP TMS320F243 – Dissertação de Mestrado, UFSC, Florianópolis, SC, 2001.

[2] – BATSCHAUER, Alessandro Luiz; CHELAB NETO, Anis Cezar; PETRY, Clóvis Antônio; Conversor Boost operando em condução contínua aplicado à correção de fator de potência empregando controle da corrente de entrada por valores médios instantâneos; Estudo para Mestrado, UFSC, Florianópolis, SC, 2001.

[3] – BARBI, Ivo; Projeto de Fontes Chaveadas. Edição do Autor. Florianópolis, 2001.

[4] – OGATA, Katsuhiko – Modern Control Engineering. Third Edition. Prentice Hall, New Jersey, 1997.

[5] – TMS320F/C24x DSP Controllers CPU and Instruction Set – Literature Number SPRU 160C, Texas Instruments. Jun/1999.

[6] – TMS320LF/LC240xA DSP Controllers System and Peripherals – Literature Number SPRU357, Texas Instruments. Rev. Dez/2001.

[7] – OGATA, Katsuhiko; Discret-Time Control Systems. Second Edition. Prentice Hall, New Jersey, 1994.

[8] – RAYCIK, Julio César; Simulação de um Retificador de Corrente Monofásico; Relatório desenvolvido para a Disciplina de Acionamento Elétricos – Mestrado em Automação Industrial. UDESC - Joinvile, SC. OUT, 2002.

[9] – CARDOSO, Fabiano Luz; RAYCIK, Júlio César; Filtro Ativo Monofásico; Relatório desenvolvido para a Disciplina de Correção de Fator de Potência – Mestrado em Automação Industrial. UDESC - Joinvile, SC. JUN, 2003.

[10] – BARCZAK, Czeslau L; Controle Digital de Sistemas Dinâmicos, Projeto e Análise; Editora Edgard Blücher Ltda, São Paulo, SP. 1994.