EXPERIMENTAL RESULTS FOR A THREE-PHASE AC/DC/AC PWM CONVERTER WITH HPF

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Abstract – **This paper presents an implementation of a three-phase AC/DC/AC PWM Converter with high power factor - HPF. The double IGBT universal bridge converter feeds a 2 hp, 310 V induction motor which is submitted to start-up, speed reversion and load application and removal tests. The converter operates with unity power factor and energy flow reversion during motor transients. Linear and predictive current controllers in synchronous dq reference frame are implemented and a comparison of their performance is presented in this paper. Experimental results of rectifier section of the converter are also presented and discussed.**

KEYWORDS

AC/DC/AC PWM, HPF converter, current controllers.

I. INTRODUCTION

The three-phase AC/DC/AC converter is a power converter designed to work as an interface between the line voltage and ac motor. They are broadly employed in AC electrical drives and other plants that require any kind of voltage or frequency level adaptations such as 50 to 60 Hz conversions. This converter can be studied in two parts: a rectifier and an inverter section. This article is focused in its rectifier section.

Among the various possible structures that operate as rectifier with power flow reversion, the universal IGBT bridge can be controlled to operate with either positive or negative currents. Under control, this topology presents fast response to transient condition, good voltage regulation and good ability of input current control with HPF and low THD[2][3]. In this case, the current control plays an important rule in the rectifier section of the AC/DC/AC converter due to the fact that the global performance of this converter is directly affected by this control[3]. For this reason a lot of papers were proposed in the last decade evaluating several aspects of these strategies [9][5][1][4][8][3][6].

This paper intends to compare the performance of the linear and predictive currents controllers applied to the rectifier section of AC/DC/AC converter. These controllers are implemented in synchronous dq reference frame in order to produce better results than the stationary frame implemented controllers.

II. THE AC/DC/AC CONVERTER

The general structure of the AC/DC/AC converter is shown in Figure 1.

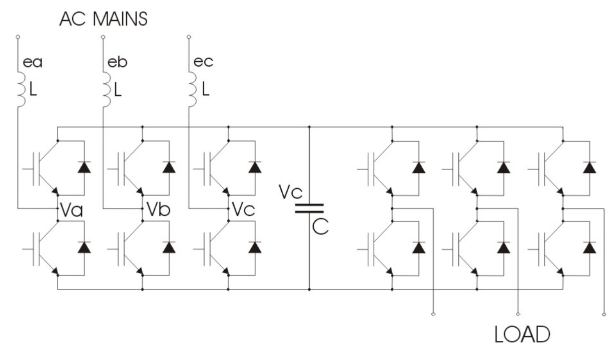

Figure 1: General structure of the AC/DC/AC converter

The voltage equations using dq rotating reference frame in an arbitrary speed "ω" can be described as:

$$e_d = Ri_d + L\frac{di_d}{dt} + v_d + \omega Li_q \quad (1)$$

$$e_q = Ri_q + L\frac{di_q}{dt} + v_q - \omega Li_d \quad (2)$$

The active and reactive power absorbed from input voltage source can be represented by:

$$p = e_d i_d + e_q i_q \quad (3)$$

$$q = e_d i_q - e_q i_d \quad (4)$$

By an orientation of d-axis in the same direction of the input voltage vector with synchronous reference frame the above equations can be rewritten as:

$$p = ei_d \quad (5)$$

$$q = ei_q \quad (6)$$

$$e_d = Ri_d + L\frac{di_d}{dt} + v_d + \omega Li_q \quad (7)$$

$$0 = Ri_q + L\frac{di_q}{dt} + v_q - \omega Li_d \quad (8)$$

III. THE CURRENT CONTROLLERS

As mentioned in the last section, the line current control is very important to obtain a good dynamical response and HPF of the drive. So, this section analyzes some popular current controllers, the hysteresis, the linear and the predictive regulators [6][3].

The classic hysteresis controller[1] presents some features such as simple implementation, over current self-protection and robustness. On the other hand, as it is well known, its switching frequency changes during a voltage period which generates undesired harmonics and switch stresses. Another problem appears due to the phase interactions and as a result the current error can be unbearable in many applications[9][5].

The linear controller[6] consists of a PI regulator and a PWM generator. The current of a phase is compared to its correspondent reference signal and the error is applied to a PI regulator. This controller presents a fixed switching frequency that generates harmonics of well-known frequencies and a reduced switch stresses in comparison to the hysteresis controller. The response of this controller can be optimized by the choice of PI gains, although it can show small amplitude and phase errors caused by the PI regulator when applied to sinusoidal signals. It also presents a relatively simple digital implementation. The steady state error can be eliminated by the use of rotating dq reference frame where signals become continuous [15].

The predictive controller calculates the voltage that will force the real current to follow its reference in each sample period based on the plant model. This controller presents a good dynamic response, but its accuracy is strongly dependent on the mathematical model showing low robustness to the load and power line parameters variations [6]. However, the more accurate is the model the more complex is controller implementation. The choice of simple model can make controller implementation very easy. Its lack of robustness can be reduced by an addition of integral gain to this controller [6]. This controller presents better results when applied to the rectifier section of the AC/DC/AC converter if it is compared to the same procedure applied to the inverter section, since that even if with the same structure, the rectifier input parameters are better known than input parameters of the inverter section.

III.1. THE LINEAR CURRENT CONTROLLER

The Figure 2 shows the control structure of the AC/DC/AC conveter with linear current controller. The PI regulators are used in voltage and current control loops. The direct-axis component of the current controls the dc link voltage of the rectifier and the quadrature one controls the reactive power, which is set to be zero assuring a unity power factor and a low THD. After coordinate transformation, compensation of the emf and application of decoupling terms *"e" "$\omega_e Liq$" and "$\omega_e Lid$"*, the resulting voltages are synthesized in PWM block.

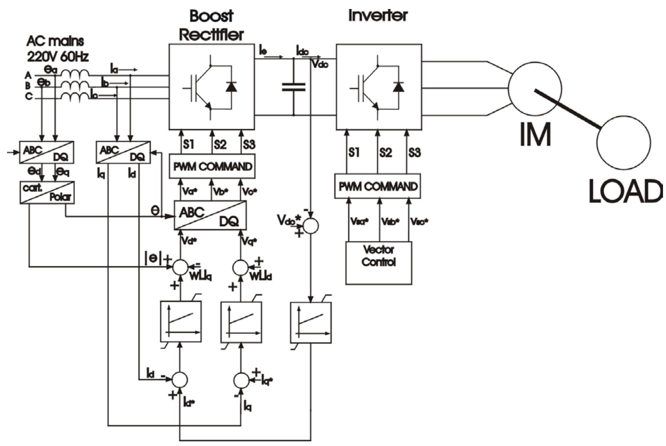

Figure 2: The block diagram for the rectifier with a linear current controller.

III.2. THE PREDICTIVE CURRENT CONTROLLER

A predictive current controller was used in the same structure of the previous section. This controller calculates the "v_d*" e "v_q*" reference voltages based on the converter model. These references will be applied to the PWM generator in the next control interval. The voltages are calculated applying discretization procedure in equations (7) and (8) [1][13]. The resulting prediction equations are:

$$v_d^*(k) = -\frac{R\left[i_d^*(k+1) - i_d(k)e^{-\frac{T_s R}{L}}\right]}{1 - e^{-\frac{T_s R}{L}}} + e(k) \tag{9}$$

$$v_q^*(k) = -\frac{R\left[i_q^*(k+1) - i_q(k)e^{-\frac{T_s R}{L}}\right]}{1 - e^{-\frac{T_s R}{L}}} \tag{10}$$

The control structure with linear current controller is shown in . Figure 3.

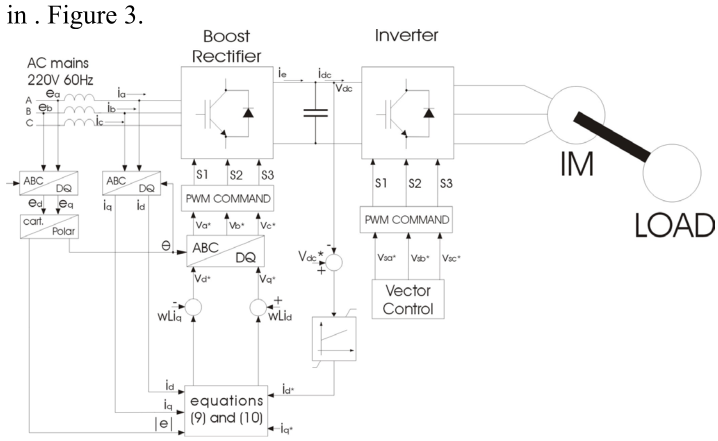

Figure 3: The block diagram for the rectifier with predictive current Controller.

Similarly to the linear controller, the emf and decoupling terms *"e" "$\omega_e L i_q$" and "$\omega_e L i_d$"* are compensated.

IV. EXPERIMENTAL RESULTS

The prototype SIAE ("Sistema Integrado de Acionamentos Elétricos") used to obtain the experimental results is shown in the picture below. The converter described before, a 2 hp induction motor coupoled to a dc generator of same power, and a PC with related hardware composes the SIAE. A Pentium 4 PC and a complementary hardware is used to communicate and to control the system. The converter based on Semikron devices is capable to supply currents until 50 A RMS at voltages up to 380 V.

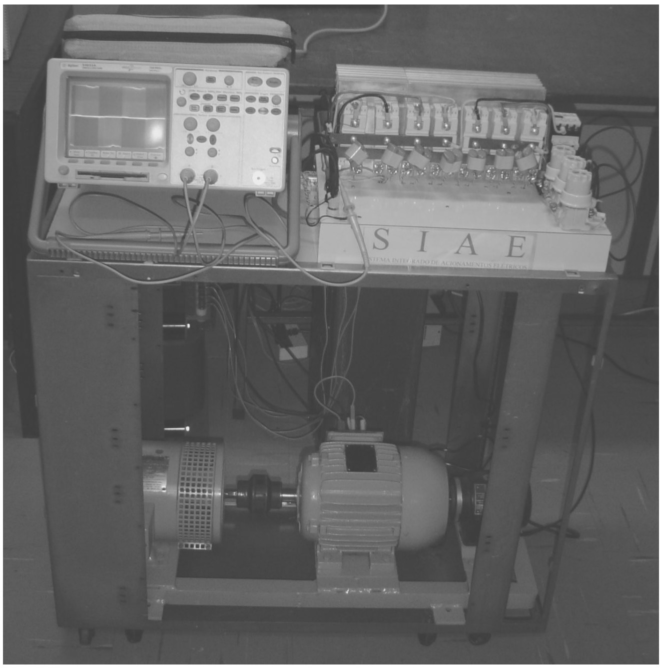

Figure 4: The Electrical Drive Integrated System - SIAE.

The results for the rectifier block of the AC/DC/AC converter were obtained by application of two test conditions. In the first test, the machine and the converter block are submitted to a start-up and a speed reversion as shown in figure 5. In the second test condition a load of 1/2 hp is applied to and removed from the machine shaft as shown in figure 6. During the test, an incandescent lamp was also connected to the dc link. Both tests were performed with a 300 V dc link reference and the machine submitted to a field oriented control [13][7].
The rectifier input voltage was adjusted by means of an autotransformer to 110 V and 80 V during the first and the second test condition respectively. A Three-Phase Regular PWM algorithm [12] was implemented with 4 kHz switching frequency. The dc link capacitor was designed to supply the power demand during the delay time in voltage loop. The inductors were designed to maintain the current ripple in a desired range [8][10][14]. The pole canceling and optimum damping strategies was employed in design of the PI regulators [11][13]. The obtained values refined by simulation and experiment and the system parameters can be seen in the appendix.

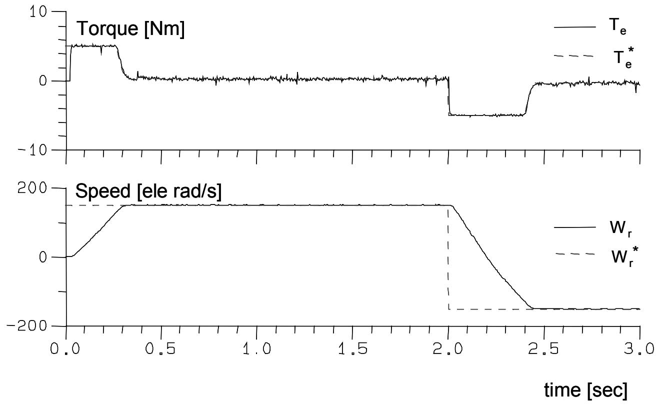

Figure 5: Motor Startup and Speed Reversal.

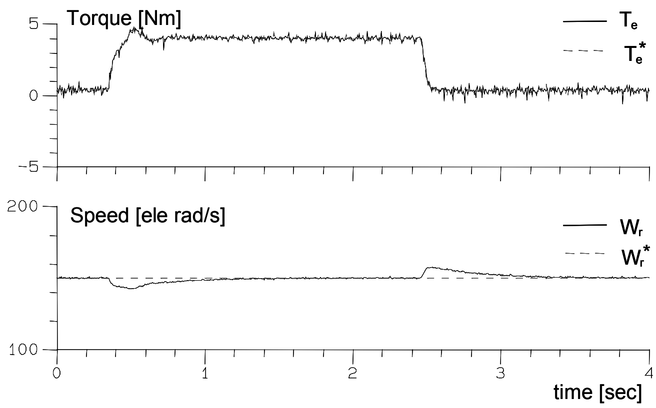

Figure 6: Motor behavior submitted to Load variation.

The figures 7 to 10 present dc link voltage, direct and quadrature axis current during the tests conditions. The figures 7 and 8 correspond to the first test condition (the start-up and the speed reversion) and the figures 9 and 10 to the second test condition (the load variation). During the start-up period, the dc link voltage presents 2 % of decrease due to the energy drained by the motor. The PI regulator compensates this voltage reduction and returns the voltage to its initial value. During speed reversion interval, although energy flows from machine to the converter which would generate an increment in the dc link voltage, the PI regulator sets a negative "i_d*" reference value in such way that energy returns to the utility. In the beginning of this interval the dc link voltage increment reaches 3 % of the reference.

The reactive power flow can be analyzed from q axis current. The Figure 7 and Figure 8 show that "i_q" current is forced to be zero and consequently the reactive power practically remains negligible all time. The d axis current shows that in order to keep constant the dc link voltage during start-up, the active power flows from the utility to the capacitor. The linear current controller presents a satisfactory response following quickly its reference. As previously expected to predictive controller the "i_d" and "i_q" current presents steady state error due to parametric sensitivity. In spite of this error the dynamical behavior is similar to linear controller.

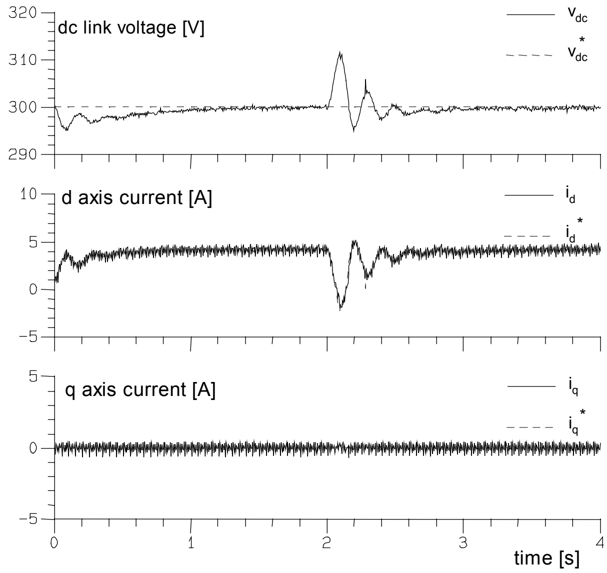

Figure 7: Startup and Speed Reversal - Linear Controller

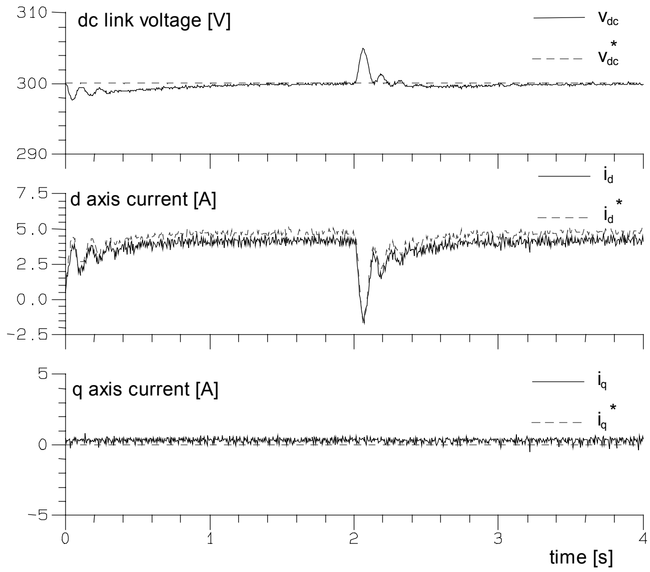

Figure 8: Startup and Speed Reversal - Predictive Controller

The load variation test results presented in figures 9 and 10 show that the voltage drop is smaller than 3 %. The d axis current rises in order to avoid the dc link voltage decreasing in the moment that the load is applied. Likewise, it becomes negative in the moment that the load is removed. After this transient, the current tends to zero. The "i_q" current behaves like it is expected, maintaining the reactive power zero.

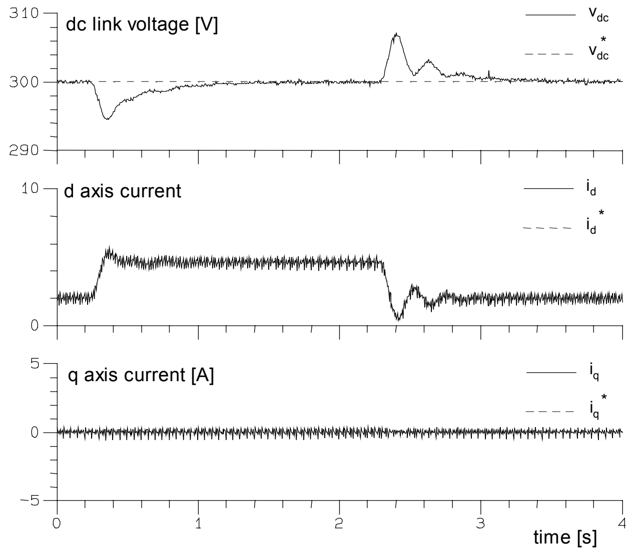

Figure 9: Load application and removal - Linear Controller

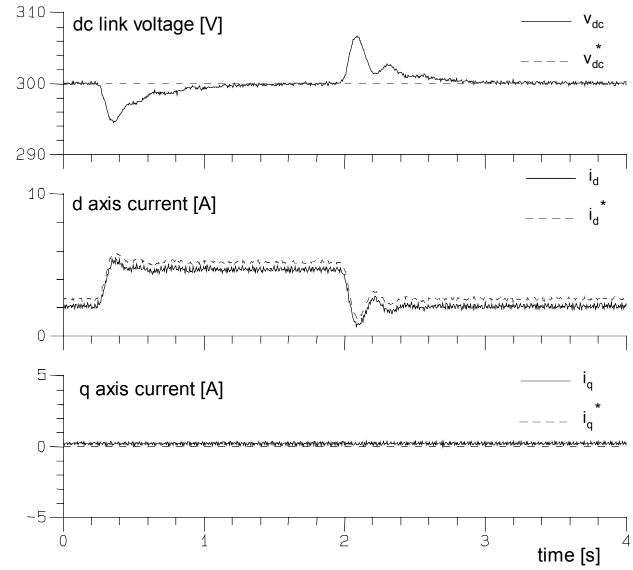

Figure 10: Load application and removal - Predictive Controller

V. CONCLUSION

The performance of the linear and predictive current controller operating in a synchronous reference frame in the rectifier section of AC/DC/AC converter was compared. The experimental results shows the efficiency of the structures to control dc link voltage and reactive power demand. The dynamical performance of the predictive controller applied to the rectifier section was very similar to the linear one. Otherwise, the steady state response of the predictive controller presented an error. This error can be eliminated through parameter adjustments or adding a PI action [6]. The last solution is efficient but presents a higher computational cost.

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APPENDIX

Inductor: L = 6 mH; R = 1 Ω;
Induction Motor:
P = 2 hp; V = 220 V ; I = 6,8 A; n = 1720 rpm

PI Regulators

Voltage Loop: kp = 0,5 and ki = 1,5;
Current Loop (Linear Controller): kp = 6,5 e ki = 900
Limit values: Imax = 8 A; Vmax = 200 V