INCREMENTAL SVM OF CONTROLLED FULL-BRIDGE RECTIFIERS TO ALLOW IEC 6100-3-2 ENFORCEMENT IN POWER GRID CONNECTION OF MODERN ELEVATOR SYSTEMS

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Abstract - **The purpose of this paper is the study of different power converters and control techniques to allow power grid connection of modern vertical operation systems, verifying IEC 61000-3-2. We focus on the harmonic current analysis produced by the industrial standard AC/DC/3-phase AC machines system. Different AC/DC converters and control techniques have been compared to determine the one that minimizes low frequency harmonic current production. An incremental Space Vector Modulator to regulate power grid current flow in electrical reference frame with a full-bridge controlled rectifier has been proven as the best power grid connection system. A general purpose test rig has been designed to evaluate the different power grid interface policies. Experimental results have been provided to show the effectiveness of the method.**

INTRODUCTION

The recent appearance of standards [3] that limit the line-current low frequency harmonic components demand new characteristics for power supplies intended for European markets. Many researchers have intensified their efforts towards finding solutions for complying these specifications, [6]-[8]. The majority of these efforts are related with cost-effective solutions based on passive filters or improving the performance of the existing power-factor correction (PFC) circuits, which require new hardware in addition to the existing one.

The elevator industry is one of the industries affected with the introduction of these new standards. In modern elevator systems, electrical machines are required. In the past, separately excited dc motors were traditionally used, mainly because their fast speed response and four-quadrant operation, with high performance near zero speed. Anyway, dc motors have certain disadvantages due to the presence of the commutator and the brushes: require a periodic maintenance, cannot be used in corrosive or explosive environments and have limited commutator capability under high-speed, high-voltage operational conditions. These problems can be overcome by the application of ac motors, which have a simple and rugged structure, high maintainability and are economical, robust and immune to heavy overloading. Their small size, compared with dc motors, allows ac motors to be designed with substantially higher output ratings for low weight and low rotating mass. The only drawback of this electromechanical system, which actually is easily solves using modern microprocessors, is the increase in control complexity for the same performance requirements as obtained using dc-machines.

Moreover, the electrical machine is used in vertical operation systems in a very particular way. First, it is operated from zero speed to nominal, positive or negative, speed and then put back to zero, while positive or negative torque loads are applied. The comfort feeling of passengers is related with a highly accurate speed and torque control, especially in low speed operation range. Actually, this functional operation is accomplished by high performance speed regulation, which requires vector control techniques of the ac machine, [4].

Although vector control techniques present better speed performance than scalar control ones (VVVF elevator drives), some payoff must be taken into account [2] like higher consumption and fluctuation on voltage and frequency which increase difficulty of these systems in controlling low-frequency harmonic current production.

Notice moreover that, with the development of power switches and microprocessor systems, full-controlled instead of diode bridge rectifiers are gaining interest on power grid connectivity of a VSI supplying induction machine especially as the power increases, which make prohibitive the use of any reactive component or regenerative resistors. Under these circumstances, the current control strategy applied is also very important to reduce the THD of the current. Current regulation has been one of the most intensively researched areas within power electronics. Traditionally, bang-bang or hysteresis current controllers, whose response times are very short, have been used. Some inherent drawbacks appear in relation with this controller: the current error is not strictly limited to the hysteresis band, there is no strategy to apply zero voltage vectors and great harmonic distortion is generated in the output current. These disadvantages restrict the application of these controllers at low and medium power levels. Other current controllers, like look-up table and sub-oscillation methods, require simple operations and provide lower current harmonic distortion. However, those methods do not provide null tracking error in steady state without high controller gains, which affect the stability of the controller. PWM strategies in field coordinates, based on the concept of voltage space vectors, are capable of producing the lowest harmonic distortion of the output current, [1]. Despite its conceptual simplicity, this current control method is computationally complex, requiring high-speed microprocessors, like digital signal processors or DSP, to its implementation.

In Fig. 1 this paper, a typical industrial AC/DC/3-phase AC machine system is studied to assure IEC 61000-3-2 complying, when connected with the public power grid. Different control methods are compared. An incremental space vector modulation (SVM) technique is proposed to reduce the low-frequency harmonic current produced by the analyzed load. A general purpose test rig has been designed to evaluate the different power grid interface policies. Experimental results provided show the effectiveness of the proposed control method.

CONTROL TECHNIQUE

The active electrical power can flow to or from the power grid depending on the electrical machine, which functions in generator and motor modes, respectively. An outer control block assures a constant DC-link voltage, generating the reference current (positive or negative) to be injected into the power grid. An inner current control block is implemented, in an electrical reference frame, using an incremental SVM. Fig. 1 presents a general overview of the proposed control technique. Notice that the proposed control method includes a simple reactive power control, allowing the user to programme a desired power factor.

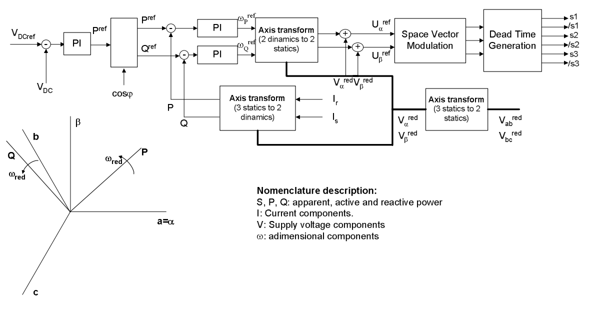

Fig. 1. General overview of the control technique

Notice that, to synchronize the generated current with the power grid voltage, a first-order coupled system that acts like a phase-locked loop (PLL) is used. It estimates the power grid voltage vector, as proposed in [9], instead of using a typical low-pass filter. The structure of the used filter is shown in equation (1) and Fig. 2.

$$\begin{bmatrix} \hat{i}_\alpha \\ \hat{i}_\beta \end{bmatrix} = \frac{kf}{(s+kf)^2+\omega^2} \begin{bmatrix} s+kf & -\omega \\ \omega & s+kf \end{bmatrix} \cdot \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{1}$$

where $\hat{i}_\alpha$ and $\hat{i}_\beta$ represents the components of the filtered vector, i_α and i_β are the components of the input vector, kf is the filter constant and ω is the center frequency for the filter.

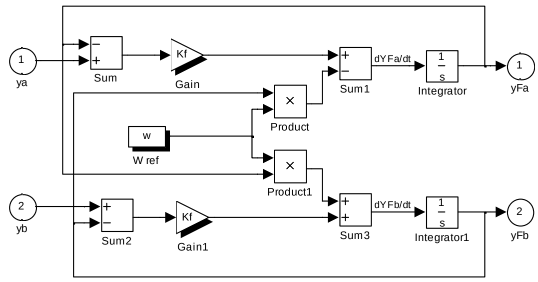

Fig. 2. Block Scheme of the proposed filter

PREVIOUS ANALYSIS

In order to study power grid connection of modern DC/3-phase AC elevator systems, a previous analysis has been made using SIMULINK tool. Different power grid connection modules and control techniques have been simulated. Fig. 3, Fig. 4, Fig. 5 and Table I sum up the results obtained. These figures represent the phase current evolution, applying bang-bang, classical PWM or space vector control methods and using different inductances in power grid connection (5 and 10 mH). Table I summarizes other simulation results. In every case, the term THD represents the total harmonic distortion observed in the output current.

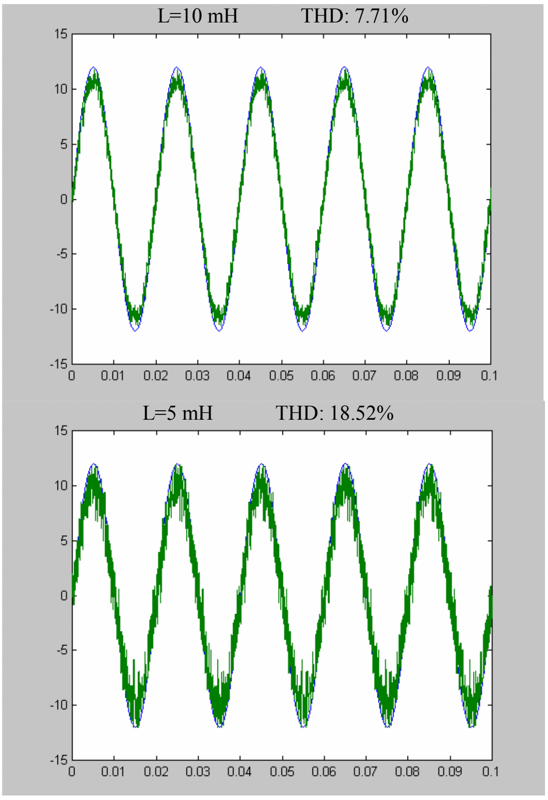

Fig. 3. Harmonic current distortion using a Bang-Bang control method

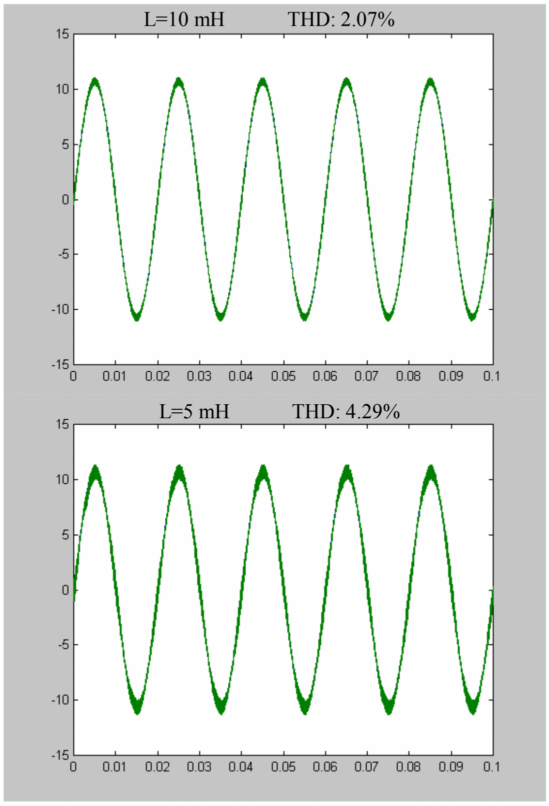

Fig. 4. Harmonic current distortion using a classical PWM control method

	Non-Controlled Rectifier	Bang-Bang		PWM		SPV	
		½ Full Load	Full Load	½ Full Load	Full Load	½ Full Load	Full Load
10mH	52.58	18.52 %	7.71 %	4.21 %	2.07 %	4.17 %	2.04 %
5mH	-	47.75 %	18.52 %	8.64 %	4.29 %	8.35 %	4.15 %
1mH	-	166.12 %	807.92 %	44.22 %	21.69 %	41.85 %	20.92 %
0.5mH	-	-	-	90.66 %	43.86 %	83.42 %	41.73 %

Table I. Theoric total harmonic distortion (THD) measured using various power grid connection inductances and load levels

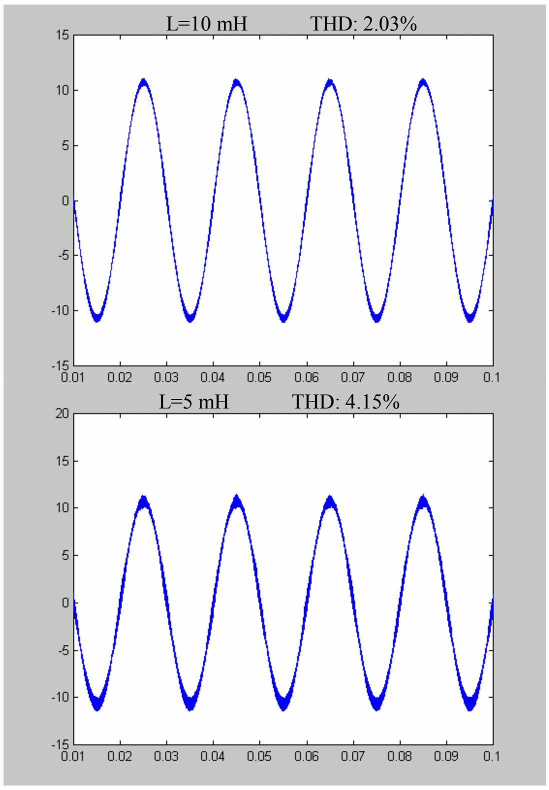

Fig. 5. Harmonic current distortion using a Space Vector method

The power module that presents better response, comparing with others, is the full-bridge controlled rectifier using the SVM technique.

EXPERIMENTAL RESULTS

To prove the effectiveness of the control system, a test rig has been designed and implemented. Fig. 6 depicts the power modules of the test rig. It is based on two electrical machines, a DC and an AC machines. The DC machine is controlled by a thyristor full controlled rectifier and it is used to emulate the elevator cabin and the load torque applied to the electromechanical system. The induction machine is connected to the power grid using two AC/DC converters and a DC-link capacitor. The first AC/DC converter is a full-bridge controlled rectifier that handles the power injected into the utility grid while the second one is engage with the induction machine control.

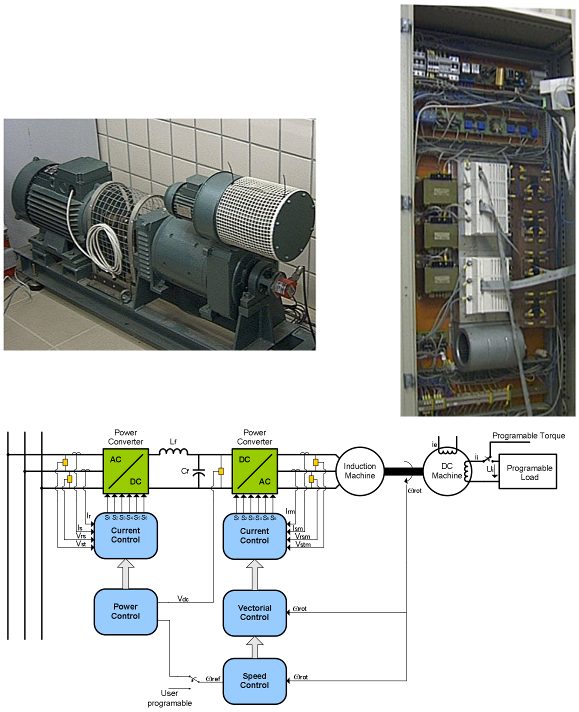

Fig. 6. Photos and simplified scheme of the test rig

A microprocessor board, based on 16 bits fixed point DSP (TMS320C243) and an ASIC has been designed to control the power system. The DSP implements the control technique of the power system connected to the utility grid. The ASIC, named ASITRON, integrates all the logic required for high performance control of induction motors and it is presently the core of a high-performance ac-drive for elevators manufactured by MACPUARSA Company. It is a highly programmable integrate that can be configured to perform 3-phase PWM current (voltage) generator, a classical voltage-frequency controller or to implement a modern vectorial control of an induction motor with a fuzzy-logic based speed and position regulation, Fig. 7.

A detailed description of ASITRON can be found in [4].

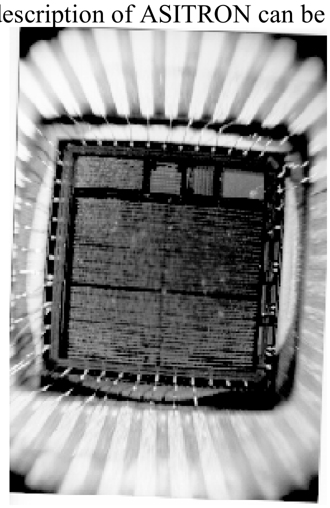

Fig. 7. Photography of ASITRON

Fig. 8 to Fig. 13 present some experimental results obtained to evaluate the performance of the system. The test rig is controlled to generate into and consume from the power grid 4kW. Power control and current waveforms are shown. Moreover, the RMS values obtained for the different harmonic current components are presented. Other values obtained from experiments are included in Table II.

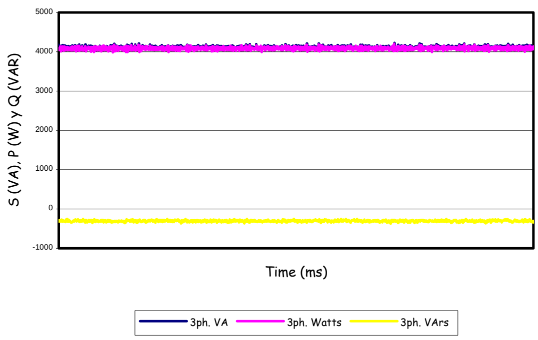

Fig. 8. Power control (active, reactive and apparent) in 4.2kW power grid consumption

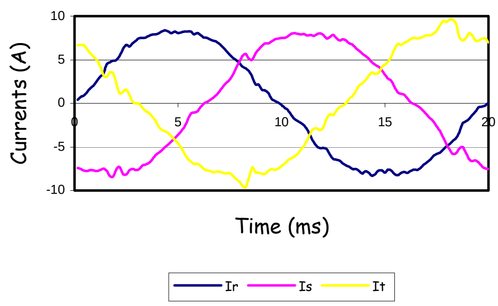

Fig. 9. Currents waveforms in 4.2kW power grid consumption

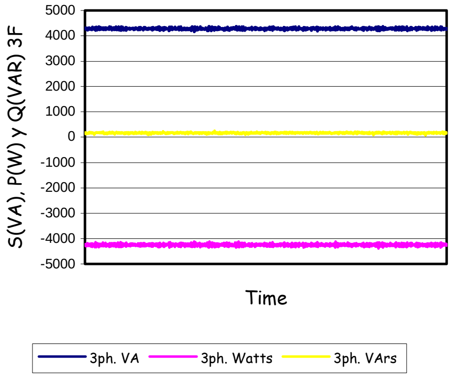

Fig. 10. Power control (active, reactive and apparent) in 4.15kW power grid supplying

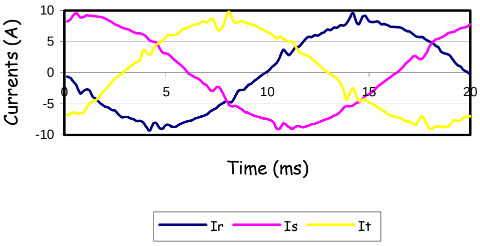

Fig. 11. Currents waveforms in 4.15kW power grid supplying

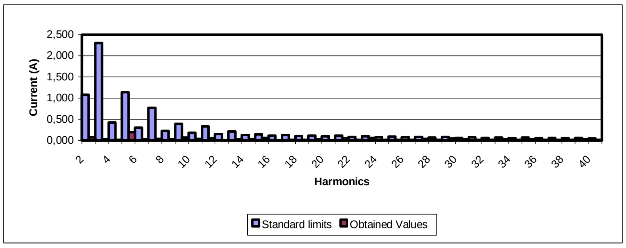

Fig. 12. RMS values of the harmonic current components (4.2kW power grid consumption)

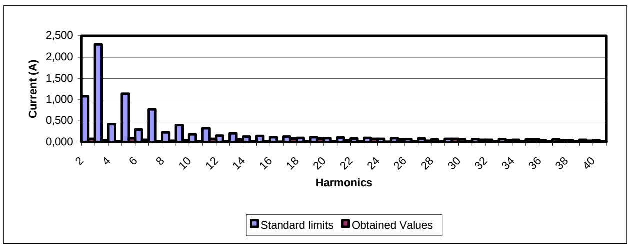

Fig. 13. RMS values of the harmonic current components (4.15kW power grid supplying)

Supply voltage reference values											
600		610		630		650		670		690	

%THD in 4.2kW power grid consumption											
Ir	Is	Ir	Is	Ir	Is	Ir	Is	Ir	Is	Ir	Is
4.6	5.9	4.8	6.3	4.1	6.9	4.8	6.7	4.9	6.9	4.84	7.6

%THD in 4.15kW power grid supplying											
Ir	Is	Ir	Is	Ir	Is	Ir	Is	Ir	Is	Ir	Is
5.6	5.7	5.7	6.4	5.4	5.7	5.4	6.2	5.5	5.9	5.1	6.4

Table II. Total harmonic distortion (THD) measured using various supply voltage controls and load levels

CONCLUSIONS

The feasibility of a modern vertical operation system to meet IEC 61000-3-2 has been assessed. A previous simulation analysis has been done to find the power module, which allows power grid connection of the system, as well as the control technique that fits the standard. Full-bridge controlled rectifiers and SVM current control techniques show the lowest harmonic distortion at the involved power level. Moreover, an incremental SVM technique has been proposed to reduce the low-frequency harmonic current produced by the analyzed load. A test-rig to evaluate control policies associated with power grid interface of a modern vertical operation system has been implemented. In addition, a microprocessor system based on a TMS320C243 DSP and an ASIC named ASITRON has been designed to control the power modules of the test rig. Finally, some experimental results have been presented to prove the effectiveness of the proposed control method.

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