A Current Controlled Inverter Using High Frequency Transformer

D.S. Oliveira Jr, C.A. Bissochi Jr, J.B. Vieira Jr, V.J. Farias and L.C. de Freitas
Universidade Federal de Uberlândia – http://www.ufu.br
Fax: 55 34 236-0466 Phone: 55 34 236-5099
38.400-902 - Uberlândia - MG - Brazil
Email: freitas@ufu.br

Abstract - A combination of a two transistor forward converter (input) and a conventional full-bridge inverter (output) with current control loop is proposed, resulting in an isolated inverter.

The forward converter operates in high frequency switching through a fixed frequency hysteresis controller, making the load current modulation.

Due to the forward current modulation, the full-bridge inverter switches in ZVS mode at turn on, and operates with low frequency switching (load operation frequency). This way, IGBTs can be used, allowing a high power output.

I – INTRODUCTION

A combination of a two transistor forward converter (input) and a conventional full-bridge inverter (output) with current control loop is suitable to impose sinusoidal current to the load with the advantages of an isolated structure. A high frequency operating transformer isolates the load from the power supply.

Load current is modulated by the forward converter, which operates at high switching frequency. This current then feeds the DC inverter link. In order to increase performance and reduce EMI, a non-dissipative commutation cell [1], [2], [3], [4] can be easily implemented in this converter.

The output topology consists of a full-bridge single-phase converter using low frequency switches that are turned on in ZVS mode, characterizing a non-dissipative commutation. Since this inverter operates in a low frequency range, IGBTs may be employed and the application in high power rate becomes feasible, depending exclusively on the isolating transformer design. Another great advantage of low frequency operation is the reduced EMI level.

This converter can directly feed any load that demands imposed sinusoidal current with low harmonic content, because it controls the amplitude, frequency and phase. It is adequate for loads which require isolation from the power source.

Sinusoidal current feeding is particularly interesting in electric machine drives, since this is the main requirement to obtain a high dynamic performance from the point of view of torque control response.

In order to feed three phase loads, three single phase converters can be used and, in view of the low cost of power electronics components, the employment of three structures is viable.

II – PROPOSED CONVERTER STRUCTURE

The combination of the forward converter with the full-bridge inverter proposed is shown in Fig. 1. As described above, the first converter feeds the DC link and the second operates as a conventional low frequency full-bridge inverter.

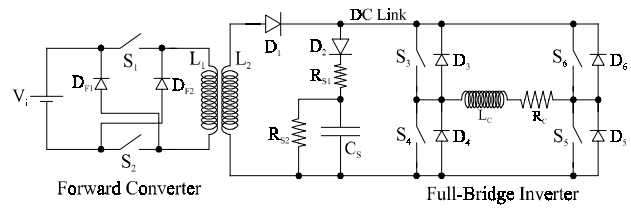

Figure 1 - Proposed Inverter Circuit

III - OPERATING PRINCIPLES

During each high frequency switching cycle, the proposed circuit operates exactly as a conventional two switches forward converter. Therefore, the duty cycle is modulated in order to impose a rectified sinusoidal current in the DC link while switches S_3, S_4, S_5, S_6 are commanded to provide the low frequency output ac current. As it can be seen in Fig. 2, these switches are turned on and off according to the load current frequency.

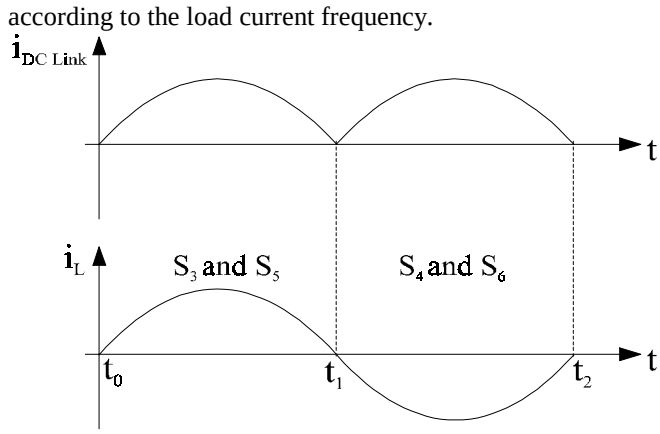

Figure 2 – Full-Bridge Operating Stages

This converter has two stages for each load current half cycle, as follows:

For the positive semi-cycle:

First Stage - S_1 and S_2 are operating in PWM switching, defining the shape of the DC link current, and

S_3 and S_5 are on, constituting the positive semi cycle of the output current (Fig. 3).

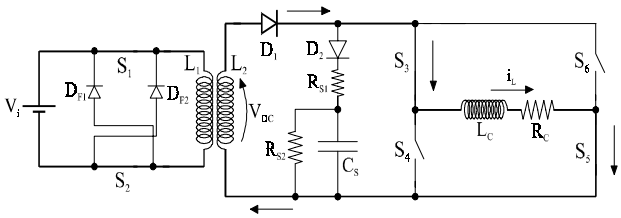

Figure 3 - First Stage

Second Stage - In this stage, S_1 and S_2 are off and S_3 and S_5 are still on. The magnetizing current flows through diodes D_{F1} and D_{F2} and the load current flows through S_5 and D_4 (Fig. 4).

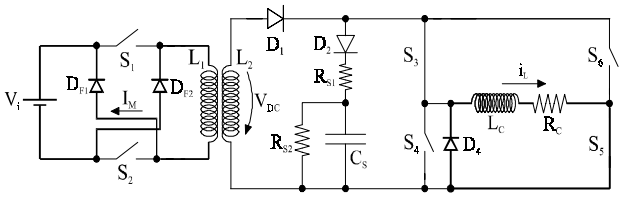

Figure 4 - Second Stage

The negative semi-cycle is analogous, with S_4 and S_6 turned on in the first stage, and with load current flowing by D_5 and S_4.

Note: During the transition from one half-cycle to another (zero crossing current), S_1, S_2, S_3, S_4, S_5 and S_6 are off. Load current flows through the freewheeling diodes D_4, D_6 and D_2 during the transition from positive to negative and D_3, D_5 and D_2 during the transition from negative to positive. The load current is then forced to zero, allowing the beginning of a new high frequency switching cycle.

IV – CONTROL CIRCUIT

The control block diagram used for simulation is shown in Fig. 5.

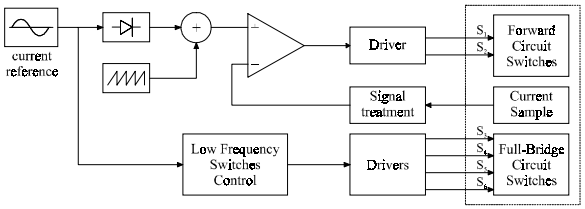

Figure 5 – Control Block Diagram

The forward converter switches are driven by the fixed frequency hysteresis current controller [5]. A load current feedback signal is compared to the rectified sinusoidal reference signal added to a high frequency, low amplitude sawtooth waveform. The pulses generated from this comparison command the forward switches, providing current modulation and imposition

V - SIMULATION RESULTS

The converter proposed was simulated in PSPICE, setting the following parameters:

V_{IN}	310V
L_1	4,3mH
L_2	10mH
C_S	50μF
R_{S1}	0
R_{S2}	50kΩ
L_C	10mH
R_C	5Ω

The reference current was adjusted for an output peak current of i_L=0,5A, 50Hz.

Fig. 6 illustrates the load current following the hysteresis band (reference).

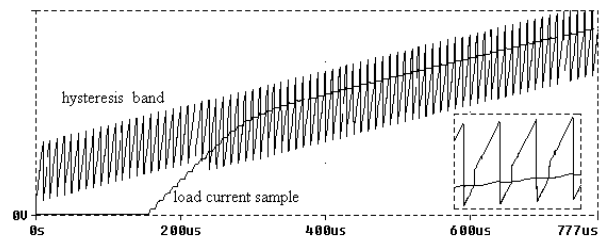

Figure 6 – Current Controller

Fig. 7 shows the sinusoidal waveform obtained from simulation of an isolated current controlled inverter, operating with R-L load, considering the forward converter operating at 100kHz and the full-bridge circuit operating at 50Hz. The harmonic distortion rate obtained from the load current is about 3%.

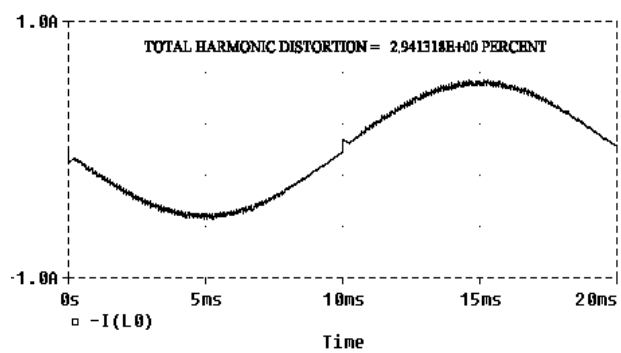

Figure 7 –Sinusoidal Load Current Waveform

VI – EXPERIMENTAL RESULTS

A prototype of the proposed converter was built and tested. The following waveforms were obtained for V_i = 100V, R_{S1} = 50kΩ, L_1 = 4,3mH, L_2 = 10mH. The load used in the experiment was a 1/12 HP motor

Fig. 8.a shows the voltage on S_2, and 8.b shows the primary transformer current. These waveforms are similar to

the waveforms obtained from any conventional forward converter. From these waveforms, sinusoidal current modulation and transformer demagnetization can be noticed. It can also be noticed that at the end of each cycle, S_1 and S_2 are naturally opened by the controller's behavior with inductive loads, which makes the full-bridge switching secure.

Fig. 9 shows the voltage and current waveforms on S_4. It can be noticed that during one half cycle, load current flows by S_4 and during the other half cycle a freewheeling stage occurs through S_4.

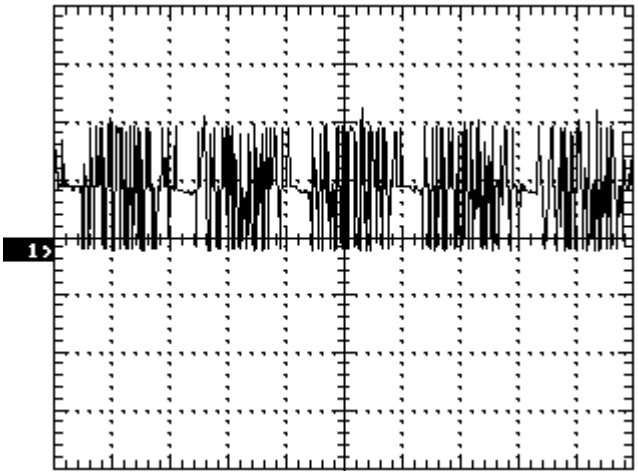

Figure 8.a –Voltage on S_2

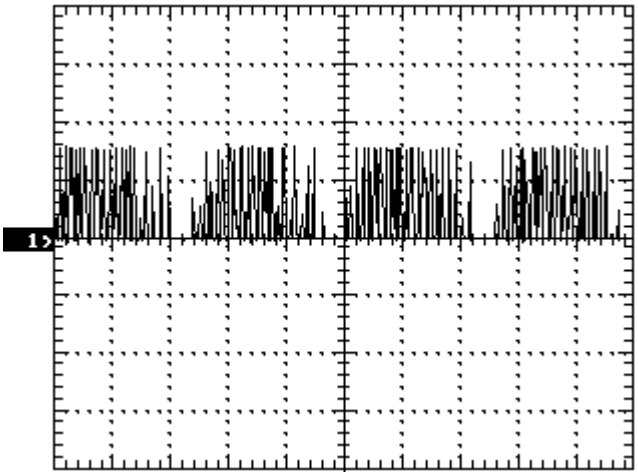

Figure 8.b – Primary Current

Figure 9.b illustrates the inductance load effect. At the ending of each half cycle, forward switching stops and freewheeling is made by S_4.

Finally, figure 10 shows the current load. A harmonic distortion around 5% was obtained. Figure 11 shows the harmonics in the current waveform.

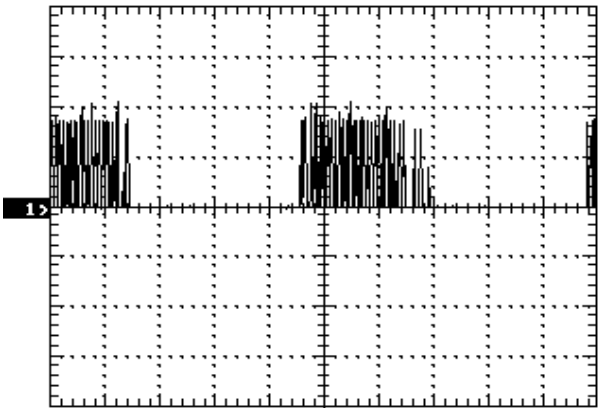

Figure 9.a – Voltage on S_4

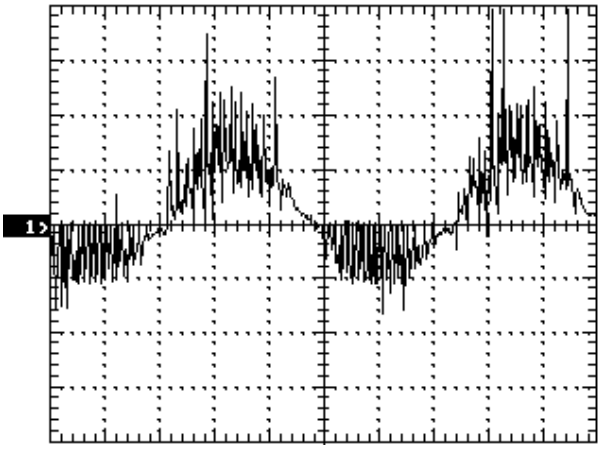

Figure 9.b – S_4 Current

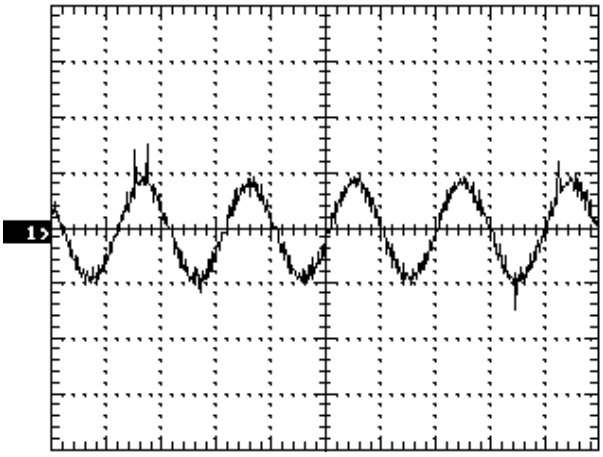

Figure 10 – Load Current

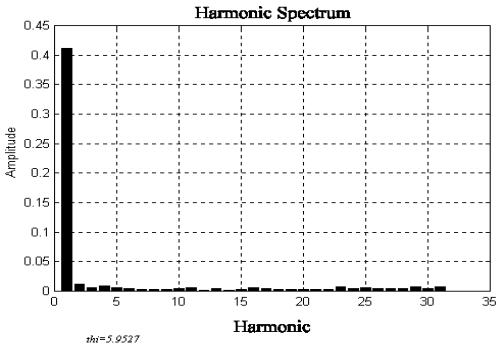

Figure 11 – Current Harmonic Spectrum

When the reference signal frequency is decreased, the control compensates with smaller duty cycles, maintaining a sinusoidal load current waveform.

If frequency is increased, voltage supplied must be higher, and increased duty cycles applies this voltage levels. Then, maximum working frequency is determined by the transformer ratio and the maximum duty cycle.

Similar behavior was noticed in amplitude variation situations.

VII – CONCLUSIONS

In this paper, a current controlled isolated inverter was presented. It was designed for loads that require not only controlled current but also isolation.

The control circuit drives the load current to follow the reference signal with good accuracy. Considering that this converter is a new topology and that further studies will come, the 5% harmonic distortion rate obtained in the load current waveform can be reduced.

Besides, this topology can be used in motor control, where isolation is needed, since this inverter controls amplitude, phase and frequency of the load current. A suitable control strategy for this application can be implemented employing a microprocessor, that is able to receive the current feedback signal and command the switches.

VIII – REFERENCES

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