A 400A Buck Converter for Welding Applications

6th Brazilian Power Electronics Conference – COBEP'2001

Sérgio Marques*, Cícero Cruz*, Fernando Antunes* and Jesualdo Farias**
*Control and Energy Processing Group – GPEC / **Mechanical Eng. Dept.
Dept. of Electrical Engineering
Federal University of Ceará – UFC
Caixa Postal 6100 – 60455-760 – Fortaleza – CE - Brazil
lsergio1@matrix.com.br - http://www.gpec.ufc.br

***Abstract* – The present paper deals with the project of a stepping-down dc-dc converter to control the current during a welding process. A hysteretic current control was implemented to guarantee a constant average current during the welding process. The main power circuit is a buck dc-dc converter that uses a high power IGBT module as the main switch. The freewheel path is made up of three parallel diodes. The buck converter was designed for an average load current of up to 200A. A microcontroller-based interface was developed to make it easier the hardware configuration. A temperature sensor fixed on the IGBT heat sink provides an indication of the temperature on the switch for monitoring purpose.**

The converter characteristics are described. Simulation and the experimental results, with the buck converter connected to the output of a conventional electromagnetic power source, are presented to show the performance of the structure.

I. INTRODUCTION

Soldering processes were, for the great majority, based on the manual process with coated electrode. The reason is that the process is cheap and simple when compared to welding processes with voltaic arc [1,2 e 3]. Welding with coated electrode commonly uses electromagnetic power sources, that are absent of a mechanism for precise control of the current during a welding action. The current control is limited to the adjustment of the impedance (reactors and transformer) of the electromagnetic power source [2]. Two instantaneous currents with the same average value, but different ripple amplitudes, produce weld beads with different quality. When a conventional electromagnetic welding power supply is used, the dynamic welding current can vary in a large range around the set average value. To archive good quality in welding process with conventional welding machines a well experienced operator is necessary. To make the welding process with good quality, some kind of automatic current control is imperative. The buck converter has a characteristic of current source at its output, so a buck converter structure along with hysteretic current control has been suggested as an option to realize the task. The electronic regulator here proposed is intended to force the dynamic welding current to stay constant or vary within a short range independent of the operator ability. The desired feature of this power electronics module for welding purpose is the ability to impose two current levels, one when there is an electric arc between the electrode and the working surface and the other one during the short circuit, when there is no arc. In order to control the average current as well as the current ripple either during the short circuit or during the arc, the electronic regulator is connected between the electromagnetic power source and the welding bed.

Simulation and experimental results on a real electromagnetic soldering source are shown to access the performance of the whole system.

II. THE BUCK CONVERTER

The buck converter structure designed, simulated and implemented in laboratory is represented in Figure 1.

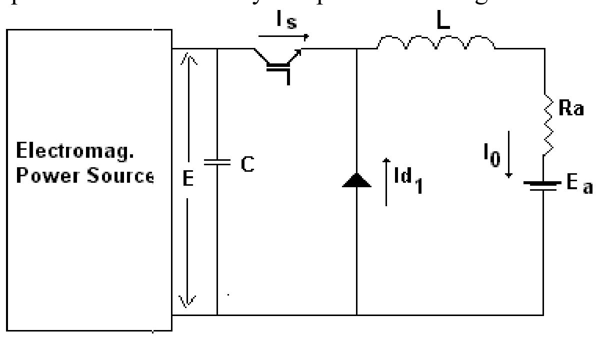


Fig. 1 - The Buck Converter.

Equation (01) to (07) describe the relation between the average load voltage, average load current I_0, the switch current I_S and voltage V_s and the power supply voltage E. The switching frequency is not constant due to the hysteretic current control [4,6].

The average values of output voltage V_0, current through the controllable switch I_S, load current I_0 and the current through free-wheeling diode D_1 are represented as a function of the duty cycle D in equations (01) to (04).

$$D = \frac{t_c}{T} \tag{01}$$

$$V_o = D \cdot E \tag{02}$$

$$V_S = (1 - D) \cdot E \tag{03}$$

$$I_{D1} = I_0 - I_s \tag{04}$$

The load current as a function of time may be expressed during the conduction time of the main switch, and also during the conduction interval of the freewheeling diode by equations (05) and (06) respectively, where R_a is a resistance and E_a is a emf modeling the voltaic arc.

$$i(t) = \frac{(E - E_a)}{R_a} \cdot (1 - e^{-\frac{t}{\tau}}) + I_o \cdot e^{-\frac{t}{\tau}} \tag{05}$$

$$i(t) = I_o \cdot e^{-\frac{t}{\tau}} - \frac{E_a}{R_a} \cdot (1 - e^{-\frac{t}{\tau}}) \tag{06}$$

There is a limitation for the duty cycle when operating a RLE load. The reason is that the power could become negative if the duty cycle is less than the rate between the emf E_a and the power supply voltage E. If they have the same value, the power flow will be null. This limitation may be expressed by the following relation [5]:

$$\frac{E_a}{E} \leq D \leq 1 \tag{07}$$

Extreme values modulation is a current control technique which makes the converter to work with a variable switching frequency. The converter maximum frequency of operation f_{max} as well as the minimum turn-on tc_{mim} time the switch can operate may be calculated by equations (08) and (9) [5] :

$$f_{\max} = \frac{E}{4 \cdot L \cdot \Delta I} \tag{08}$$

$$t_{c_{\min}} = \frac{\Delta I \cdot L}{E} \tag{09}$$

To operate in continuous conduction mode, the inductor current must never be null. So, it is important to determine the critical value of the inductance, which sets the boundary for continuous and discontinuous mode of operation. The critical inductance is determined by equation (10). The energy storage element of this power converter is an air core inductor. A non-magnetic core has been chosen due to the fact that the silicon-iron material cannot be used as magnetic core in high frequency operation because the losses would become very high. The only problem is that an air core inductor is bigger, when compared to a magnetic one. The inductance value has been determined by equation (11) [4]. A large capacitor C has been included at the input of the buck converter in order to make the input voltage as steady as possible.

$$L_{cr} = \frac{E}{8 \cdot f \cdot I_0} \tag{10}$$

$$L = \frac{N^2 \cdot \mu_o \cdot \pi \cdot D^2}{4 \cdot l} \tag{11}$$

III. BUCK CONVERTER SPECIFICATION

A conventional welding machine is made of a step-down three-phase transformer em series with a three-phase ac-dc converter. The rectified dc voltage is about 90V. Knowing that the voltage across the soldering bead can vary from 16V to 40V with an average current of 200A, the buck converter is specified for the following characteristic: Input voltage 90V, average output current 200A. The buck converter has to have a capacity to process power up to 8kW [7]. The converter operates with a variable switching frequency, but considering the time constants of the process, for the sake of project, a frequency of 20kHz has been used. According to the input and output voltage specifications, the switch duty-cycle will vary between 0.18 and 0.44. The average switch current is 89A. For an average load current of 200A the average freewheeling diode current is 111A. The input capacitor is rated to 88,220μF. This is a very large value because of the low frequency of operation and the power level of the converter [7].

A air core inductor has been used because of the frequency of the converter which rules out a ferromagnetic core. Its inductance is 112,5mH with a diameter of 15cm and a length of 25cm. Considering the size of a welding machine, the inductor was well accommodated.

IV. SIMULATION RESULTS

The whole system has been designed for values in accordance to conventional electromagnetic power supplies for welding applications. So, the buck converter was simulated for an average current of up to 200A and a ripple of 10A over any operating condition. This controlled ripple value is provided by extreme values current control technique. The transient current during the short circuit may assume a 400A maximum level.

Using the PSPICE circuit simulation software, some curves were plotted to describe the power stage of the system. Only the power structure of figure 1 was simulated. The load current was controlled between the defined extreme values. Figure 2 represents the load current. Figure 3 is the current through the main switch.

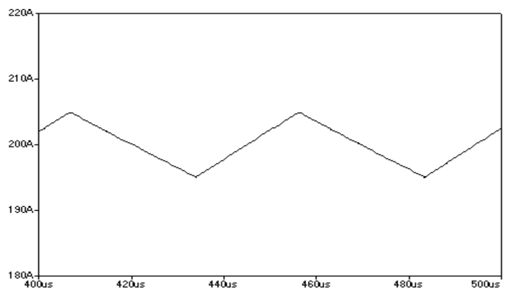


Fig. 2 - Controlled Welding Current

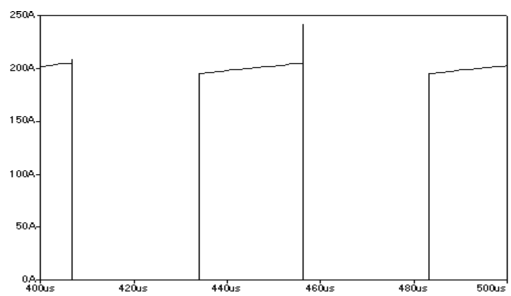
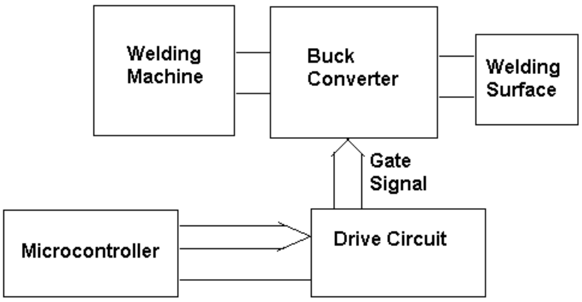


Fig. 3- Instantaneous Current Through the Main Switch

V. LABORATORY PROTOTYPE

In order to verify the performance of the proposed buck converter, the module has been placed in between the conventional uncontrolled welding machine and soldering surface. The laboratory prototype has been implemented according to the block diagram shown in Fig.4.



.

Fig. 4 - Experimental Set up Block Diagram

The dc-dc buck converter was implemented using the following components: a SKM400GA102D IGBT for 1000V and 400A, three parallel 70HFL60s02 diodes each one with a 70A current capability and a 112μH air core inductor designed and manufactured using equations (08) and (12). These components have been chosen in order to permit the welding current control module to be used with any off the shelf electromagnetic welding machine, and to make it possible the Buck converter realize the current control without excessive stress.

Figure 5 shows the power stage laboratory set up.

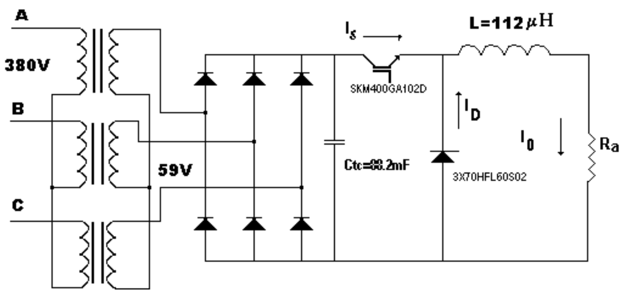


Fig. 5 - Power Circuit Set-up

The capacitor C_{tc} has been introduced in the circuit in order to improve the voltage source characteristic at the dc-dc converter input. Considering that during the welding process the load voltage could vary between 16V and 40V, and the average load current can reach 200A. A conventional snubber circuit (not shown in Fig.5) has been connected across the IGBT switch in order to limit the overvoltages due to stray inductances [7].

Fig.6 is a schematic of the the circuit to detect a short circuit during the welding process, and if is the case, to change the reference current during the short circuit. The voltaic arc occurs for voltages in between 16V and 40V [7]. Any voltage well below to 16V characterizes a short circuit situation.

The load current is continuously monitored using a Hall effect device. The output current of the Hall effect device is forced to circulate through a 1Ω resistor that develops a potential difference across its terminals proportional to the load current. This voltage is then amplified and compared to a reference voltage. The comparator uses a positive feedback to promote the hysteresis band. If the amplified signal is greater than the upper limit of the comparator, a low signal is generated and sent to drive the IGBT. This control signal forces the IGBT to turn off. When the amplified signal is lower than the lower limit of the hysteresis comparator, a high signal is generated and the IGBT is driven to the conduction state. This mechanism realizes the current control. The level of the current to be controlled is set through a microcontroller-based interface.

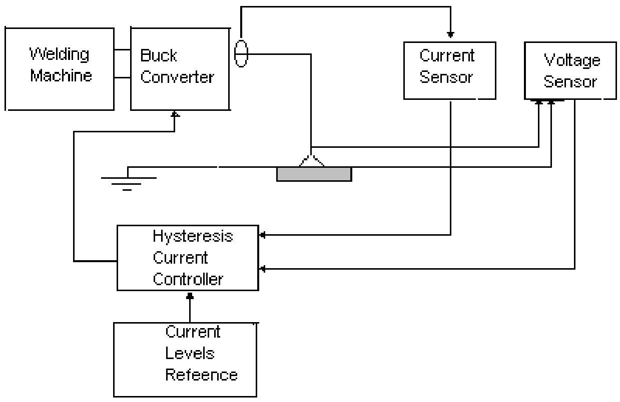


Fig. 6 – Current Control Schematic

VI EXPERIMENTAL RESULTS

This section presents practical results which illustrate the performance of the proposed system. The load current has been set for a 10A ripple, despite its average value. Figure 7[1] shows the current waveform through the IGBT.

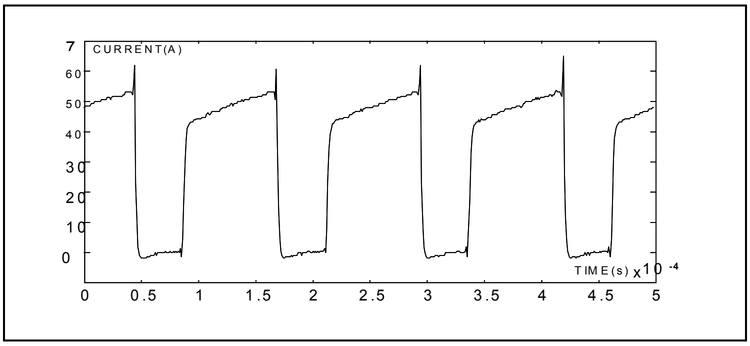


Fig. 7 - The IGBT Current

[1] - At the time of data acquisition, the current probe had a maximum current capability of 50A.

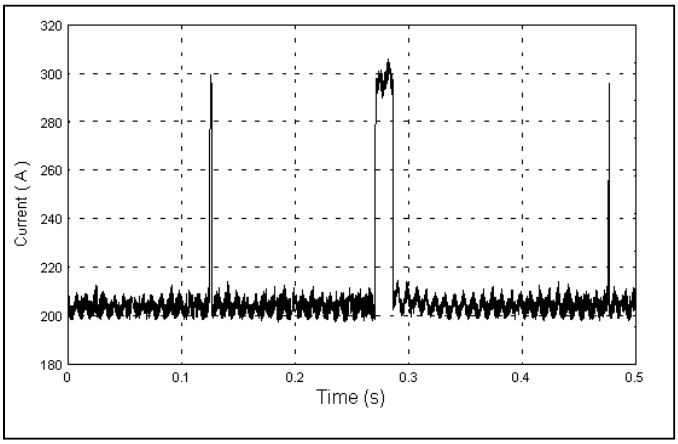


Fig. 10 - Controlled Welding Current

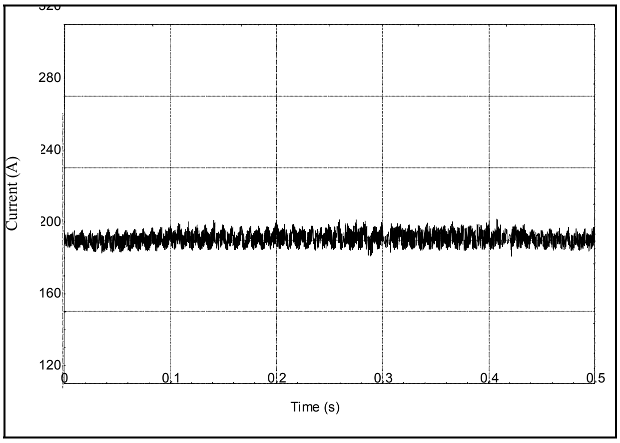


Fig. 8 – Load Current

The performance of the current controller as far as the ripple in the load current is concern, is represented in Fig.8, where, the established 10A load current ripple is guaranteed by the current control.

Figure 9 shows the instantaneous load current of a conventional welding machine without the current control operated by a well-experienced technician during a welding process. Fig.10 shows also the load current during the same welding process, but with the introduction of the current control structure. In that case, the current was set with the same value either during the voltaic arc or during short circuit situation. To show the ability of the structure to set two levels of current control, one during the voltaic arc and the other one during a short circuit situation, Fig.11 shows the welding current for an average current of 200A during the voltaic arc and 400A during a short circuit situation. It is also shown in the same figure the output voltage during the welding process.

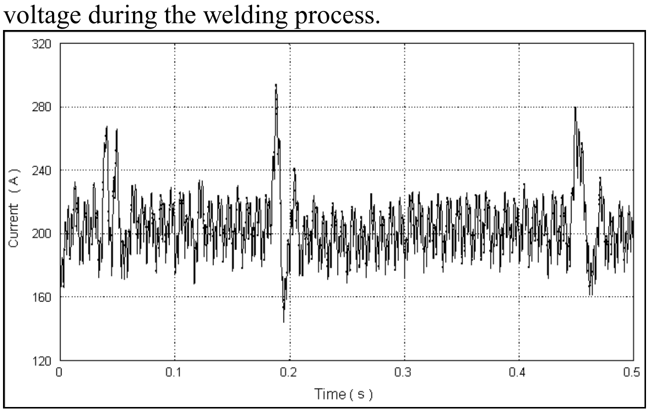


Fig.9 - Uncontrolled Welding Current

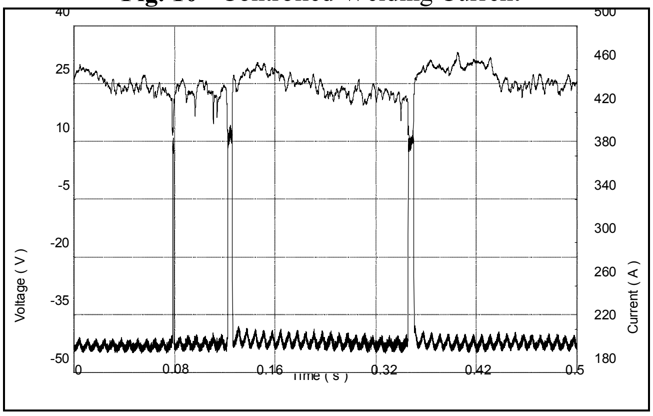


Fig. 11 - Current and Voltage During a Welding Process. Upper Trace: Voltage. Lower Trace: Current

VII. CONCLUSION

This paper has proposed a power structure and its control circuit to improve the quality of the welding process with conventional welding machines, where the quality of the weld bead depends upon the self-ability of the operator. The designed buck converter operated as expected and can be used with any off the shelf welding machine. The power circuit implemented, necessary for the current control, is rated at 8kW (40V, 200 A)

VIII. ACKNOWLEDGMENT

This work was supported in part by Agência Nacional de Petróleo – ANP and Companhia Energética do Ceará - COELCE.

IX. REFERENCES

[1] - Norrish, J. (1992), Advanced welding processes, IOP Publishing LTD, Filadelfia and New York, USA.
[2] - AWS (1991), Welding handbook, vol. 2, Welding Process, 8th Ed.
[3] - AWS (1991), Welding handbook, vol. 1, Welding Fundaments, 8ª Ed.
[4] - Rashid, M. H. "Power Electronics: circuits, devices and applications". Prentice-Hall International Editions, 1999.

[5] - Barbi, I. “Eletrônica de potência”. Florianópolis. Ed. do Autor 1997. (in Portuguese)
[6] - Kassakian, J., G., Schlecht, M., F. and Verghese, G., C. "Principles of Power Electronics". Addison Wesley Series in Electrical Engineering, 1991.
[7] - Marques, Sérgio. “Controle da corrente de soldagem através de um conversor buck utilizando a técnica da modulação por valores extremos“, Master Degree thesis, UFC, 1997. (in Portuguese)