Step down Converter with Sliding mode Current Control for Welding Applications

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***Abstract*— The present paper deals with a buck converter used to control the current during a welding process. The arc is modeled by a variable resistance in series and switcher to create a short circuit. The step-down dc-dc converter is connected to the output of a step down transformer witch present the power source and it controls the energy flux to the welding process.**

A sliding mode current control was implemented to guarantee a constant average current during, the arc generation. The main power circuit is a buck 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 a load current up to 100A.

Simulations results are presented to show the performance of the structure.

***Key words*—control process, arc welding, power converter, power electronics.**

I. INTRODUCTION

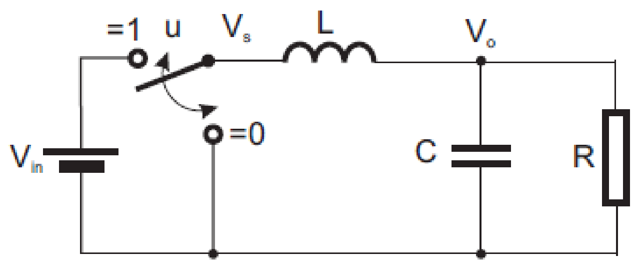
The quality of a welding process may be improved if some variables are well adjusted [1,2,3]. The current is one of them. A low ripple current who has the same medium value of another one with greater ripple, produce welds beads with different qualities. So, to get a better result from each condition of welding, a study must be done about the current influence on it. The system here proposed is suitable for the realization of this study. The desired features from this power electronics module for welding are the ability to impose two current levels, one when there is an electric arc between the electrode and the work and the other one during the short circuit, when there is no arc. In order to control the current ripple in both situations mentioned above a buck converter has been suggested as an option to realize the task.

The reasons are its simple configuration, the fact that there is a large literature about it and the energy store element is placed on the load side.

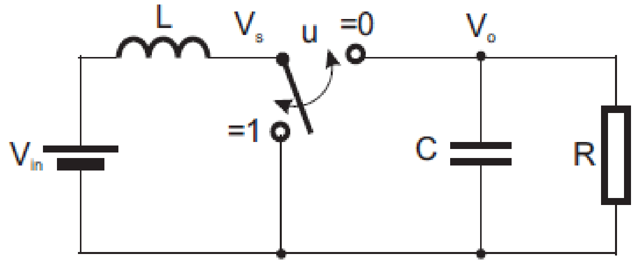
II. THE DC-DC CONVERTER

There are three kinds of switching mode DC-DC converters, buck, boost and buck-boost. The buck mode is used to reduce output voltage, whilst the boost mode can increase the output voltage. In the buck-boost mode, the output voltage can be maintained either higher or lower than the source but in the opposite polarity. The simplest forms of these converters are schematically represented in Figure 1.

a -Buck-



b – Boost-



c -Buck –boost

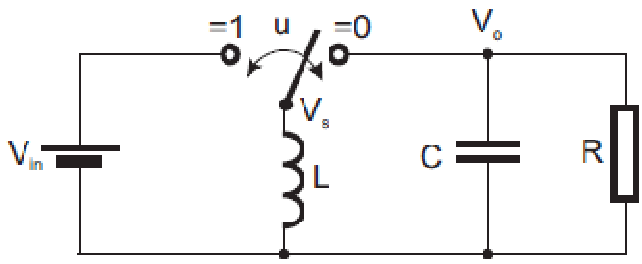


Fig 1. Switching-mode DC-DC converters: (a) buck, (b) boost and (c) buck-boost.

These converters consist of the same components, an inductor, L, a capacitor, C and a switch, which has two states u = 1 and

u = 0. All converters connect to a DC power source with a voltage (unregulated), V_{in} and provide a regulated voltage, V_o to the load resistor, R by controlling the state of the switch. In some situations, the load also could be inductive, for example a DC motor, or approximately, a current load, for example in a cascade configuration. For simplicity, here, only current and resistive loads are to be considered.
The converter adapted in our paper is the first one –the buck converter-.

A . Principles

The working principles of these DC-DC converters can be explained as follows. In the buck mode, when the switch is on position 1, the DC source supplies power to the circuit which results an output voltage across the resistor. When the switch changes its position to 0, the energy stored in the inductor and capacitor will discharge through the resistor. Appropriately controlling the switching position can maintain the output voltage at a desired level lower than the source.

The buck converter [4] designed, simulated is shown in Figure.2

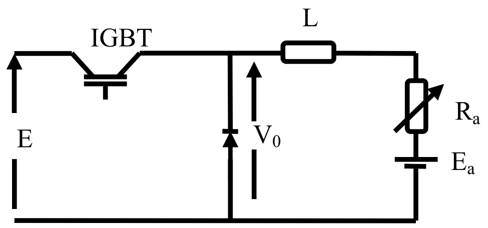


Fig.2 Buck converter.

The equations below describe the relation between the load voltage, load current, switches current, voltage and the power supply. The duty cycle D may be constant or variable. When the PWM control is used, the switching period (T) is not variable. In the case of extreme values control, the frequency is variable [4-6].

$$v_0 = D.E \tag{1}$$

$$D = \frac{t_c}{T} \tag{2}$$

$$V_{IGBT} = (1-D).E \tag{3}$$

$$i(t) = I_0 e^{\frac{-t}{\tau}} + \frac{E_a}{R_a}\left(1-e^{\frac{-t}{\tau}}\right) \tag{4}$$

The load current as a function of time may be expressed during the conduction time of the main switch and when the freewheeling diode is forward biased through equations (5) and (6) respectively.

$$i(t) = \frac{(E-E_a)}{R_a}\left(1-e^{\frac{-t}{\tau}}\right) + I_0 e^{\frac{-t}{\tau}} \tag{5}$$

$$i(t) = I_0 e^{\frac{-t}{\tau}} + \frac{E_a}{R_a}\left(1-e^{\frac{-t}{\tau}}\right) \tag{6}$$

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

$$L = \frac{N^2.\mu_0.\pi.D^2}{4.l} \tag{7}$$

To operate on continuous conduction mode, the inductor current must never be null. So, it is important to determine the critical value of the inductance (L_{cr}) which sets the boundary for continuous and discontinuous mode of operation. Equation (8) helps to determine it. The energy storage element of this power converter is an helicoidal air gap inductor. The reason to use it comes from the fact that the iron-silicon material is not used as magnetic core when operating in high frequencies because the losses become very high. The only problem is that with an air core the inductor gets bigger. It can be designed using Equation (9) [4].

$$L_{cr} = \frac{E}{8.f.I_{load}} \tag{8}$$

$$S = \frac{de}{dt} + Ke \tag{9}$$

The IGBT and the diode are not linear components. Their models were approximated by resistances. The resistance has a high value when the specified semiconductor is not conducting the load current and it is low when its current is equal to the load current, figure 3 show the block diagram of the converter welding power sources.

III. Sliding Mode Control

Sliding mode control is a control method in changing structure control system. Compared with normal control, it has a

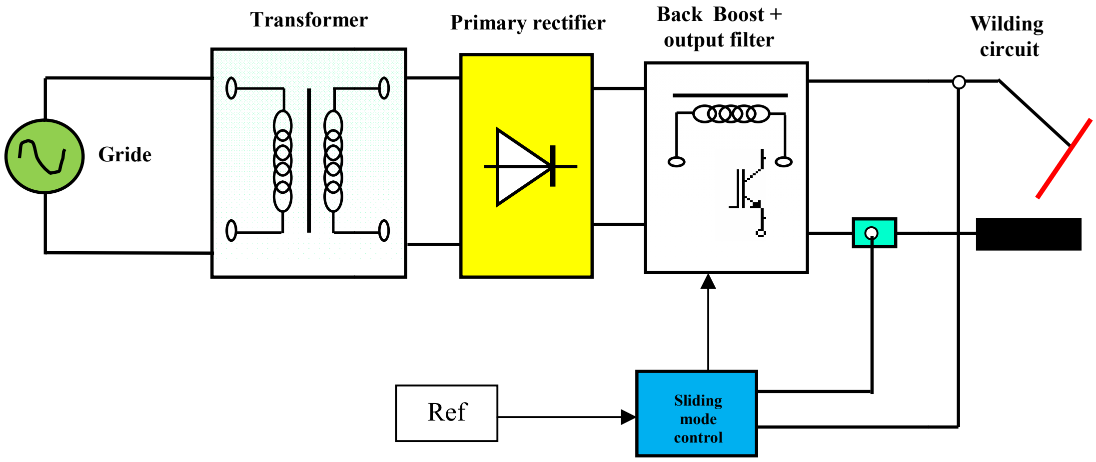


Figure.3 The block diagram of the conveter welding power sources.

Switching characteristic to change the structure of the system with time.[7] Such characteristic can force system to make a fluctuation with small amplitude and high frequency along state track under determinate trait which can also be called as sliding mode movement. System under sliding mode has good robustness because the sliding mode can be designed and it has nothing to do with parameters and disturbances of the system. Theoretically speaking, sliding mode control has better robustness compared with normal continuous system, but it will result in fluctuation of the system due to the discontinuousness of the switching characteristic [6,7]. This is one of the main drawbacks of the sliding mode control and can't be avoiding as the switching frequency cannot be infinite. However, such effect can be ignored because high accuracy of voltage control is not required in welding power source.

Set inductance current i_L and capacitance voltage v_c as variables, by using state-space average method, the equation of phase-shift full-bridge is:

$$\dot{i}_L = -\frac{1}{L}v_0 + \frac{1}{L}D.E$$

$$\dot{v}_0 = \frac{1}{C}i_L - \frac{1}{R_L C}v_0$$

Where ***D*** is duty cycle

Choose voltage error as the state variable for the system:

$$e = i_L - i_{ref}$$

$$\frac{de}{dt} = \dot{i}_L = -\frac{1}{L}v_0 + \frac{1}{L}D.E$$

Then, Besides choose the switch function:

$$S = \frac{de}{dt} + Ke$$

$$S = -\frac{1}{L}v_0 + \frac{1}{L}D.E + k\left(i_L - i_{ref}\right)$$

$$\dot{S} = -\frac{1}{L}\dot{v}_0 + \frac{1}{L}D.\dot{E} + k\,\dot{i}_L$$

$$\dot{S} = -\frac{1}{L}\left(\frac{1}{C}i_L - \frac{1}{R_L C}v_0\right) + \frac{1}{L}D.\dot{E} + k\left(-\frac{1}{L}v_0 + \frac{1}{L}D.E\right)$$

$$\frac{1}{L}D.\dot{E} \simeq 0$$

So,

$$\dot{S} = -\frac{1}{L}\left(\frac{1}{C}i_L - \frac{1}{R_L C}v_0\right)$$

Let $$\dot{S} = 0 = \frac{1}{LR_L C}v_0 - \frac{1}{LC}i_L = 0$$

To meet the requirements of sliding mode control

$$\dot{S}.S \le 0$$

In order to verify the performance of the buck converter with the sliding mode current controller, a simulation of the dynamic of the process is done by considering the following tests:

The first test concerns a no-load starting of the welding machine with a reference current I_{ref}= 100 A. Then creation of arc welding at t=3s

The second one concerns a changing in current reference passing from 100 to 120A.

Using the simulink circuit simulation software, some curves were plotted to describe the power stage of the system.
The load current was controlled between the defined extremes. The Figure 4 represent the load current and its zoom respectively. Figure 5 is the voltage behavior of the buck converter. The drive pulse is represented by Figure 6.

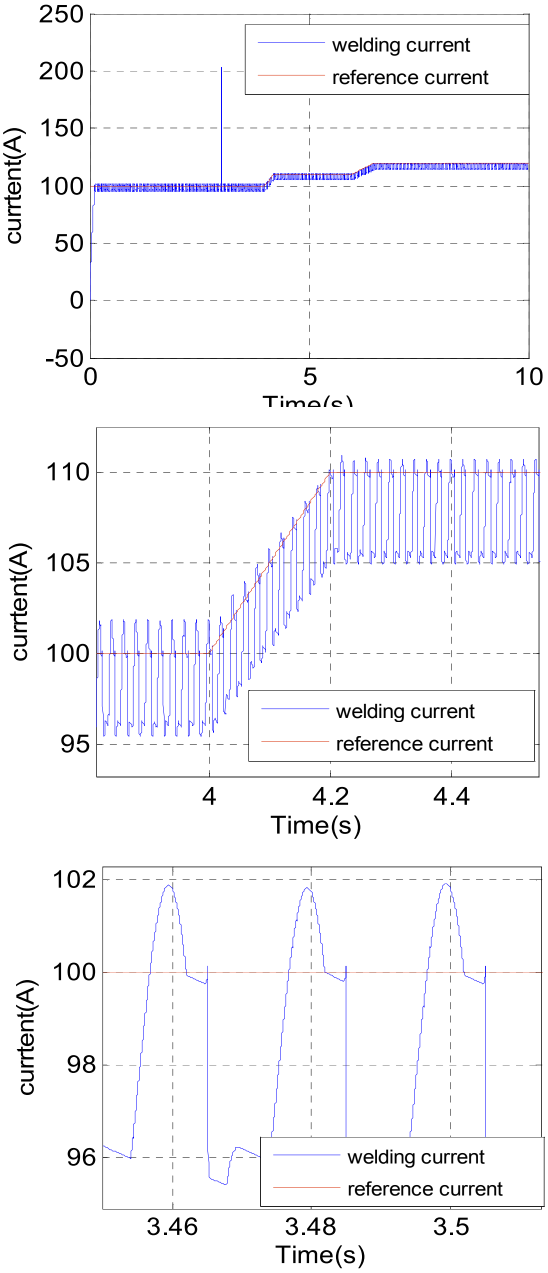


Figure 4 The welding current i_L

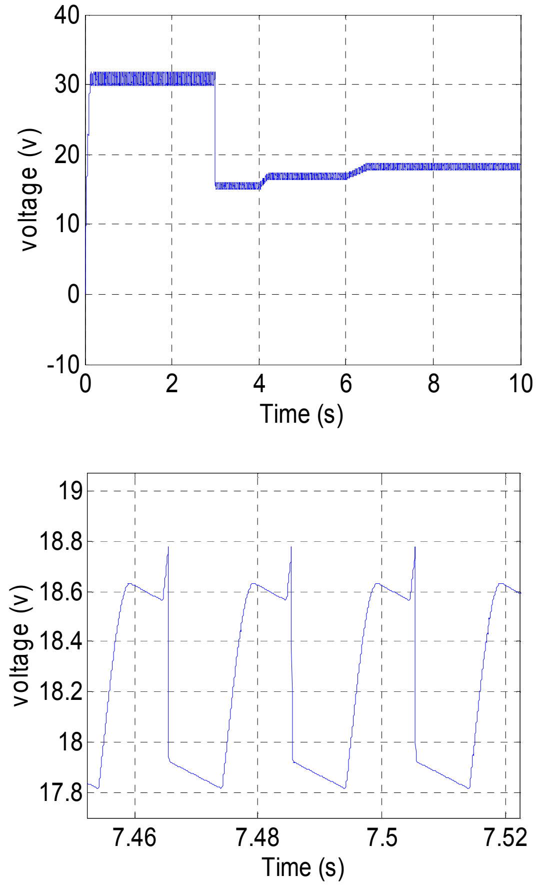


Figure 5 The behavior of the converter

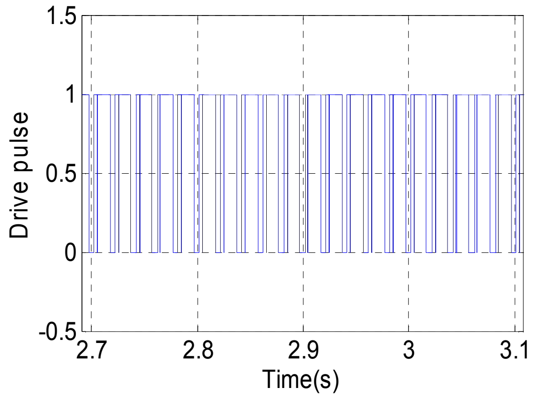


Figure 6 The drive pulse of the IGBT

Figure 4 show the output current with sliding mode control starting without load until t= 3s, where the arc welding was generated with peak current and drop voltage (figure 5), it can seen that the current follow its reference with small variation due to the chattering phenomena generated by the sliding control, the zoom in figure 4 show a variation in welding current, it increase until 102A and decrease until 96A and same variation can be seen in the output voltage (figure 5)

which is due to the variation in resistance between the cathode and the peace work, this last is a result of variation in distance from the peace work.
Figure 6 show the drive pulse of the IGBT as a result of caparison between reference signal generated by sliding controller and career signal realizing the PWM technique.

IV. CONCLUSION

The system proposed in this paper opens the possibility 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 control of the current during voltaic arc represents another way to improve it.
The sliding mode control proposed in this paper has good dynamic performance and easily applied algorithm, and is very suitable for arc welding buck converter power source which requires good dynamic performance for the control system.

V. REFERENCES

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