A ZVS FULL BRIDGE CONVERTER FOR WELDING APPLICATON

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Abstract – This work presents the development of a welding machine based on a Zero-Voltage-Switching Phase-Shift Full-Bridge DC-to-DC isolated converter. The Dc-to-Dc Full-Bridge converter is controlled by a technique that naturally guarantees soft commutation in all active switches. No additional devices are employed to achieve the soft switching condition. Due to phase-shift modulation, the current is equally shared among main switches, reducing the converter conduction losses, when compared with conventional pulse width modulation. The control strategy employs a digital technique with two levels of output voltage. The high level of output voltage is controlled with no load in the output and the low level one is controlled when the electrode is welding. It is presented the design procedure and simulation results.

***Keywords* – DC-to-Dc full-bridge converter, soft switching, welding machine.**

I. INTRODUCTION

Welding in the simplest terms is the process of fusing or joining two or more metal pieces with the application of heat and pressure. Resistance welding uses the concept of heat generated due to the current flowing through a resistance. The heat energy generated in the process is large enough to weld two work-pieces together [1]. Arc welding is the process based on melting a material to join two work-pieces together. In the arc welding an electrode is melt to become altered from a solid to a liquid state usually by heat using a high level of electrical current. When the material becomes cold the two pieces are joined in a solid structure.

Arc welding portable machines are very used in Brazil for small repairs or in small company's process. There are two main classifications for arc welding machines: conventional and electronically controlled [2]. The conventional technique do not have an adequately control of the current in the welding and the work quality is poor. In the electronically controlled machines it could be made a good control of the level current and its ripple, then resulting in a very good quality of the weld work.

Controlling the current level in the welding machine the user could adapt the conditions required to each application then could control the quality of the weld. Some methods are used to control the current in arc welding systems. It could be used a circuit applying thyristor phase control with a low frequency transformer or a DC to DC converter with high frequency transformer [2]. High frequency DC to DC converters increase the weld machine controllability and reduce the system weight and volume.

II. CONCEPT OF ARC WELDING

The weld bead is formed from both the melted electrode and the melted base metal. Therefore, an investigation of alternate heat sources must consider the total quantity of metal which is melted to form the weld deposit. Two parameters which relate directly to the formation of the weld deposit are the penetration depth and the cross-sectional area of the weld bead. Studies of the welding arc heat distribution have shown that higher welding speeds more efficiently use energy melting. It has been shown that the amount of fused base metal increases with increasing welding current, and that voltage does not significantly affect the weld bead cross sectional area [3]. Weld deposit formation depends on the intensity of the arc energy transferred to the base material and the influence of fluid flow in the weld pool.

The melting efficiency has been defined for both the electrode and the base material. Melting efficiency measures the amount of arc energy that is used to melt the electrode and the amount of arc energy available to melt the base plate. Melting efficiency relates the physical dimensions of the weld deposit of the energy input from the arc, and it is used as a measure of the heat evolved and used to melt the weld nugget during exothermically-assisted welding. This parameter is evaluated using calorimetric data to determine the potential of chemically-assisted welding electrodes [4].

The mechanism by which plate melting occurs during arc welding is not well understood [4]. However, three major influencing factors that have been identified are:

a) heat generated from the cathode/anode potential drop zones;
b) heat generated from the arc column, and
c) the superheat of the molten metal from the electrode.

The heat generated in the arc plasma is dependent on the welding current and voltage. Thus, the higher the current and/or voltage the higher the amount of heat generated. The higher the heat generated in the arc plasma, the greater the plate melting.

In practical arc welding application it is used the output current control to vary the heat generated. The voltage has no control and is dependent on the current circulating through consumable electrode and base plate. Doing this, the heat generated is dependent on the welding current.

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III. PROPOSED CONVERTER AND OPERATION

A DC to DC converter for welding application needs to feed adequately levels of current and voltage for each welding process. Furthermore it needs to allow the adjustment of the current and/or voltage level for specific applications.

The DC to DC converter output should have current source characteristics with two levels of voltage. In the welding process the voltage level is low and when no current is circulating in the electrode a high voltage level is permitted.

A very high variety of DC to DC converter topologies is suitable for arc welding applications. To decide the better one is not an easy decision.

Some topologies of forward converter could be applied, but they need additional devices to achieve soft-switching, reduced conduction losses and high power application [5].

The Full-Bridge converter is suitable for high power application and could operate with soft-switching condition if some modification is made in its topology.

The Phase-Shift Full-Bridge converter [6] is a good choice. It has a suitable level of power for arc welding applications and a good controllability of the output current. But it uses additional devices to achieve soft commutation.

Some contributions were made in recent years to intend applying multi-level converters to reduce the voltage level stress in the active switches [7, 8, and 9]. These converters have interesting characteristics like low level of voltage in the active switches, but they use additional devices to achieve soft commutation. Furthermore they present a high level of current in the active switches when compared with the Phase-Shift Full-Bridge converter.

In this work it is used a modified Zero-Voltage-Switching Phase-Shift Full-Bridge converter (ZVS-PS-FB) to implement an arc welding machine. This converter is based on the ZVS-PS-FB topology presented in reference [10]. The proposed converter is shown in Fig. 1.

The converter does not need additional devices to achieve soft commutation and has a high power capability suitable for arc welding applications.

The proposed converter consists of four active switches (S1-S4), a high frequency transformer (Tr), two output diode rectifiers (D1 and D2) and an output inductor (L) to serve as a current source. The resistance (R) represents the resistance of the electrode and the base plate.

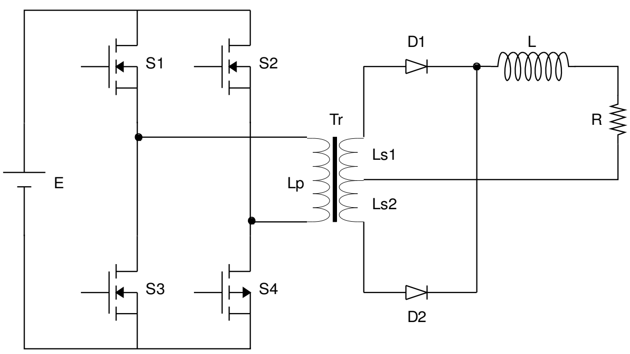

Fig. 1. The proposed ZVS-FB converter for welding application.

The parasitic devices not shown in Fig. 1 are used to achieve the soft commutation condition. The MOSFET intrinsic capacitors and transformer leakage inductance form the resonant circuit that allows the converter commutate in a soft switching way. The MOSFET body diodes are used like the free wheeling diodes. No output capacitor is needed for welding process.

The gate drive signals are shown in Fig. 2, where it is represented the phase-shift time (ps) and the dead time (dt) required for an adequate operation. In this type of control the power level transferred to the load is controlled by varying the phase-shift time between the two switch legs (S1-S3 and S2-S4). For a low phase-shift time a high power level is delivered to the load. On the other hand for a high phase-shift time a low power level is delivered to the load. The dead time is necessary to allow the soft switching converter operation and to prevent short circuit. The four switches pulse width (pw) is maintained constant and the switches in each leg are driving complementarily, facilitating the converter design and implementation. The gate signals are generated using a dsPIC30F2020 micro-controller.

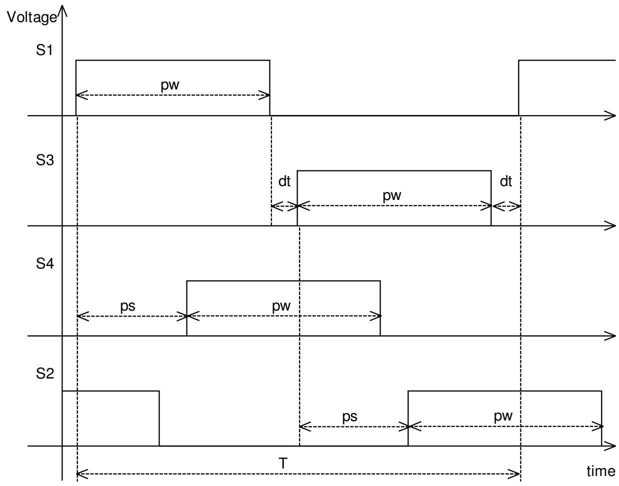

Fig. 2. The basic gate drive signals.

Power is transferred to the output only in the moment when the gate signals of switches S1 and S4 or S2 and S3 are superposed. Then the duty cycle (D) is defined as the double of the difference between ps and pw.

$$D = 2\,(pw - ps) \qquad (1)$$

IV. DESIGN PROCEDURE

In order to design the converter it is used the methodology proposed in [10]. Initially, some specifications are defined:

$Po = 2kW$ (Output Power)
$Vo = 25V$ (Output Voltage)
$Io = 80A$ (Output Current)
$Vi = 311V$ (Input Peak Voltage)
$f = 50kHz$ (Switching Frequency)

Defining the delay time $dt = 0.15$ and choosing a maximum duty cycle of 0.55, the following calculations could be made in order to design the converter.

$$n = (D\max - dt)\frac{Vi}{Vo} = 4.98 \text{ (Transformer Ratio)}$$

$$Vo' = n\ Vo = 124.4V \text{ (Reflected Output Voltage)}$$

$$Io' = \frac{Io}{n} = 16.06A \text{ (Reflected Output Current)}$$

$$Lr = \frac{dt\ Vi}{4\ f\ Io'} = 14.52\mu H \text{ (Resonant Inductor)}$$

$$L = \frac{2\ Vo\ (Dmax - dt)}{0.1\ Io\ f} = 50\mu H \text{ (Output Inductance)}$$

With these calculations one can specify the semiconductor devices. It was chosen the following devices:

APT50M38JLL – active switches S1-S4

APT30S20B – output Schottky diodes D1 and D2.

V. OBTAINED RESULTS

Some simulation results taken from a 2kW arc welding system were obtained and they are shown in the following figures.

Fig. 3 shows the output power, voltage and current at rated load. This converter presents a good stability and low oscillations in transient condition.

Figs. 4 and 5 show the voltages across and the currents through the switches S1 and S2 respectively.

Figs. 6 and 7 show the voltages across and currents through the switches S3 and S4 respectively.

In Figs. 4-7 it could be seen that the commutations occur in zero-voltage condition and the two switches pair conduct the same level of current. These characteristics are obtained like a natural result of the implemented drive strategy with no use of additional devices or artifices.

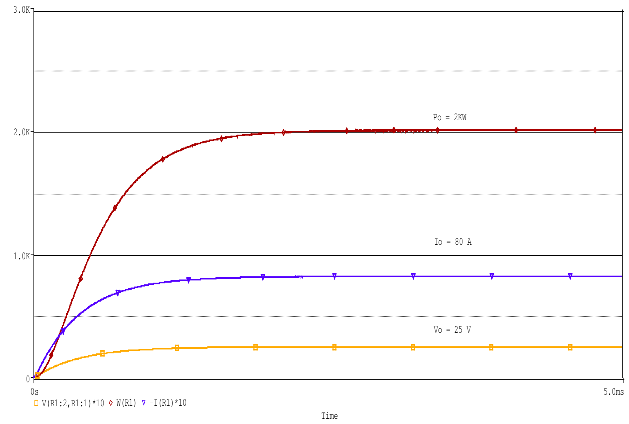

Fig. 3. Output power, voltage and current.

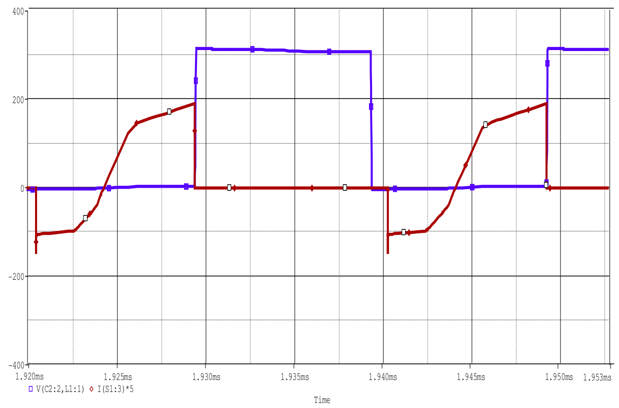

Fig. 4. Voltage across and current through the switch S1.

Figs. 4-7 also show that no additional voltage or current stress is applied to the switches and the maximum active switches voltage is equal to the input voltage source.

Fig. 8 show the voltage applied to the primary side of the transformer and Fig. 9 show the resonant inductor current. The resonant inductor is the transformer leakage inductance. The both figures prove the balanced distribution of voltage and current level applied to the transformer winding. These characteristics guarantee the entirely high frequency transformer demagnetization.

A laboratory prototype with 2kW of output power, 80A of arc welding output current and 220Vrms input AC voltage is been implemented.

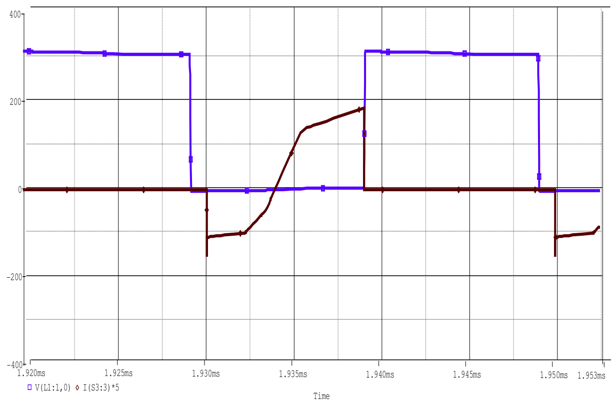

Fig. 5. Voltage across and current through the switch S3.

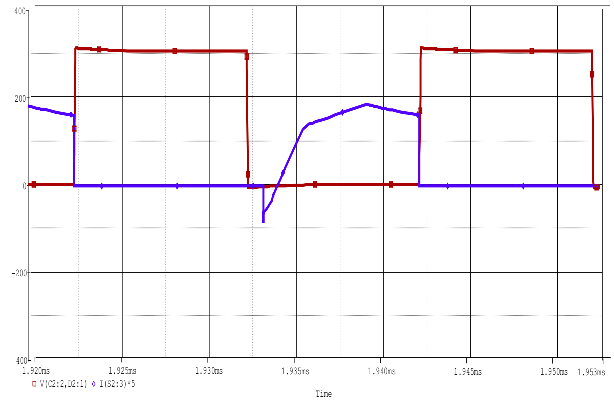

Fig. 6. Voltage across and current through the switch S2.

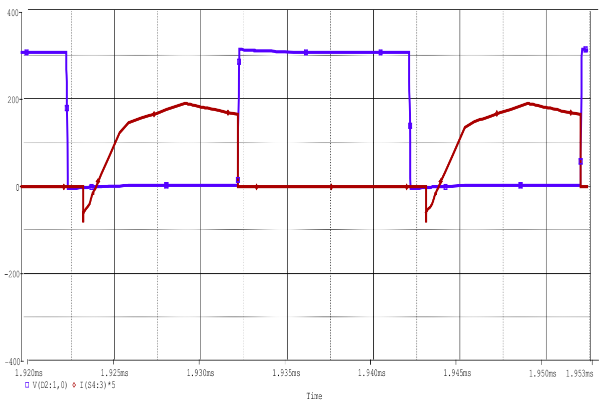

Fig. 7. Voltage across and current through the switch S4.

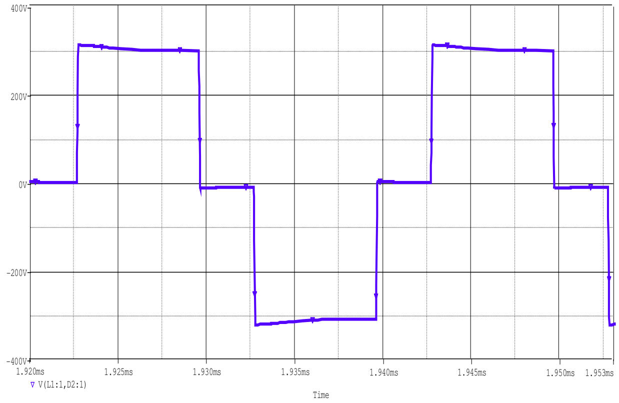

Fig. 8. Voltage applied to the primary side of the transformer.

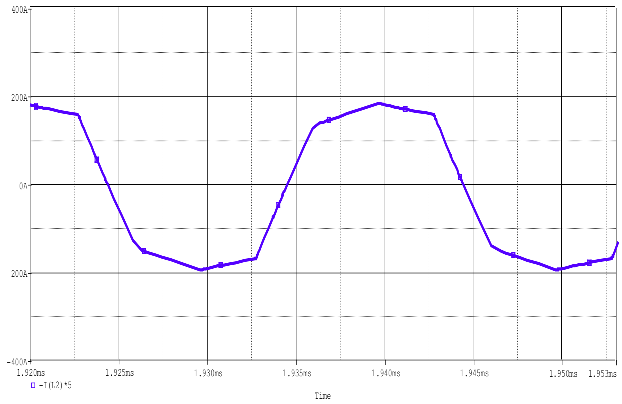

Fig. 9. Resonant inductor current.

VI. CONCLUSION

In this work was presented the development of a welding machine based on a Zero-Voltage-Switching Phase-Shift Full-Bridge DC-to-DC isolated converter. The Dc-to-Dc Full-Bridge converter is controlled by a technique that naturally guarantees soft commutation in all switches. No additional devices are employed to achieve the soft switching condition. Due to phase-shift modulation, the current is equally shared among the active switches, reducing the converter conduction losses, when compared with conventional pulse width modulation. The control strategy employs a digital technique with two levels of output voltage. The high level of output voltage is controlled with no load in the output and the low level one is controlled when the electrode is welding.

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