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Arc Welding Machine with Half-Bridge Forward Converter

Yasar Birbir
Faculty of Technology, Electrical and Electronic Engineering, Marmara University, Goztepe, 34722 Istanbul, Turkey
Email: ybirbir@marmara.edu.tr

***Abstract*—This paper presents a 3kW welding machine based on a half-bridge forward converter. It is known as the two transistor forward converter and has a primary power switch arrangement that is similar to its counterpart in the fly-back converter. This arrangement is particularly suitable for MOSFET transistor operation, as the energy recovery diodes D5 and D6 provide hard clamping of the switching devices to the supply line, preventing any overshoot during the fly-back operation. The voltage across the power switches will not exceed the supply voltage by more than two diode drops, and therefore voltage stress will be only half of what it would have been in the single-transistor, single-ended converter. In this system, the welding machine has been designed for one phase line input. This converter drives high frequency transformers with output ratings of 24V and 120A during welding process. The converter uses current mode PWM controller integrated circuit. SG1844 improves on the 100 KHz switching frequency with respect to size and weight, but the switching frequency is limited by the switch devices and transformer material. This control technique is able to ensure proper ignition with 78 V. The essential requirement for this welding machine power supply is to control the PWM wave form and adapt it for welding process. Current mode PWM controller can be achieved by using small values of the inductor and capacitor. The size and weight will be greatly reduced. They are reliable and flexible, offer good efficiency, fast response and control robustness. The unique load characteristics associated with arc plasma loads make this type of current mode PWM controlled converter well suited for arc striking. It also allows safe operation during the arc plasma state. The aim of this work was to design and build suitable power supply for a welding machine. This can be achieved by current mode switching power supply with a minimum number of external components.**

***Index Terms*—half-bridge forward converter, welding machine, fly-back converter, arc plasma, current mode PWM controller**

I. INTRODUCTION

The electric arc finds widespread applications ranging from electro heating to lighting applications. In lighting applications, a heating filament is often introduced to reduce this striking voltage, but such an approach is not practical in electro heat applications such as welding and arc furnaces. Common to these applications is the fact that a high initial voltage is required to ionize the gas before the plasma state can commence.

In recent accordance with the application of power electronics in higher quality welding machines, less spatter generation and more automation are required. Initiation of an arc plasma conduction state requires a relatively large voltage to ionize the gas. Once ionized, the arc is maintained by supplying current at a reduced voltage [1].

Generally, there are two methods for establishing an arcing process: one is touch-arcing, the other is non-touch arcing. The arcing process of the former is that the electrode touches the base metal work piece first, and then keeps a short distance apart. The latter process (also named high voltage arcing) applies a high pulse voltage source between the electrode and work piece to force arcing. It is usually necessary to equip arc ignition devices to produce the source with thousands of volts in non-touch arc welding machines. Two types of arc welding machine power sources essentially are used, constant current sources and constant voltage sources. The former regulates load currents, while the latter regulates load voltages. Moreover, in the welding process the metal transfer is performed by high temperature arc plasma, which repeats short and arc circuit state through an inverter circuit. These repeated instant transients from short-state to arc-state and vice versa might destroy the switching devices of an inverter passing through the transformer's primary coil [2].

Usually inverter welding machine has uncontrolled rectifier and dc filter capacitor for AC/DC power conversion stage. The performance considerations of the welding machine consist of output current response, current regulation, current ripple, fault tolerance, efficiency, weight and cost. In the literature, a Parallel Resonant Converter (PRC) with capacitive filter or phase- shift controlled Series Resonant Converter (SRC) has been used in these sorts of applications to yield high performance. If the output filter capacitor increases, the cost significantly increases for the applications of high voltage arcing machines, thus, somewhat limiting it from high voltage applications [3]. In this paper, it has been shown that current mode PWM controlled welding machines yield better performance than traditional machines. In the circuit, a conventional heavy weight filter inductor acting as a constant current sink source is replaced with a small filter inductor which is equivalent

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to the lumped inductance of welding cable. The output filter inductors are much larger than their resonant ones. It should be pointed out that the converter is loaded with arcing device that utilizes small inductor filters.

II. CONVERTER CIRCUIT AND BASICS OF OPERATION

The power switches MOSFET1 and MOSFET2 are turned on, or off, simultaneously. Welding machine power converter circuit is shown in Fig. 1. When the devices are switched on, the primary supply voltage VDC will be applied across the transformer primary, and the winding will go to positive polarity. Under steady state conditions, a current will have been established in the output choke L1 by previous cycles, and this current will be circulating by flywheel operation in the choke L1, capacitor C2 and load, returning via the flywheel diode D8. When the secondary emf is established (by turning on the power MOSFETs), the current in the secondary of the transformer and rectifier diode D7 will build up rapidly, limited only by the leakage inductance in the transformer and secondary circuit. Since the choke current IL must remain nearly constant during this short turn-on transient, and then as the current in D7 increases, the current in the flywheel diode D8 must decrease equally. When the forward current in D7 has increased to the value originally flowing in D8, then D8 will turn off and the voltage on the input end of L1 (node A) will increase to the secondary voltage VS. The forward energy transfer state has now been established [4].

The previous operations occupy a very small part of the total transfer period, depending on the size of the leakage inductance. The current would typically be established within 0,1μs. For the very high welding current, and low welding voltage outputs, the delay caused by the leakage inductance may be longer then the complete “on” period (particularly at high frequencies). This will limit the transmitted power. Hence, the leakage inductance should always be as low as possible. Under normal conditions, during the majority of the “on” period the secondary voltage will be applied to the output LC filter and the voltage across L1 will be (VS -Vout). Therefore, the inductor current will increase during the “on” period at a rate defined by this voltage and the inductance of L1. This secondary current will be transferred through to the primary winding by normal transformer operation, so that IP=IS/a, where “a” is the transformer ratio. In addition to this reflected secondary current, a magnetizing current will flow in the primary as defined by the primary inductance LP. This magnetizing current results in a flyback operation during turn-off transient. When MOSFET1 and MOSFET2 are turned off, the voltage on all windings will reverse by fly-back operation, but the fly-back voltage will be limited to the supply voltage by the clamping operation of diodes D5 and D6. The energy that was stored in the magnetic field will now be returned to the supply lines during the turn-off period. Since the fly-back voltage is now nearly equal to the original forward voltage, the time required for the recovery of the stored energy will be equal to the previous “on” time. Consequently, for this type of circuit, duty ratio cannot exceed 50%, as the transformer would staircase into saturation [5]. At the turn-off instant, the secondary voltage will reverse and rectifier diode D7 will be cut-off. The output choke L1 will maintain the current constant, and flywheel diode D8 will be brought into conduction. Under the forcing operation of L1, a current will now flow in the loop L1, load, D8 and node A will go negative by a diode drop. The voltage across L1 equals the output voltage (plus a diode drop), but in the reverse direction of the original “on” state voltage. The current in L1 will now decrease to its original starting value, and the cycle is completed [6].

III. CONTROL SYSTEM

The control circuit for this inverter uses an integrated circuit SG1844. IC provides 100KHz switching frequency. This integrated circuit contains analog and digital circuits. Its shape is compact with 8 pins. The SG1844 family of control IC provides all the necessary features to implement off-line fixed frequency, current mode switching power supplies with a minimum number of external components [7]. Current-mode architecture demonstrates improved line regulation, improved load regulation, by-pulse current limitation and inherent protection of the power supply output switch. The band-gap reference is trimmed to ±1% over temperature. Oscillator discharge current is trimmed to less than ±10%. The SG1844 has under-voltage lockout, current-limiting circuitry and start-up current of less than 1mA. The totem-pole output is optimized to drive the gate of a power MOSFET. The output is low in the off state to provide direct interface to an N-channel device. Both operate up to a maximum duty cycle range of zero to <50% due to an internal toggle flip-flop which blanks the output off every other clock cycle. The SG1844 is specified for ambient temperature range of -55℃ to 125℃. Block diagram of the control circuit is shown in Fig. 2.

IV. PERFORMANCE

It is important to note that the leakage inductance plays an important role in the operation of this welding machine system. Excessive value of leakage inductance results in an inability to transfer the welding power effectively, as a large proportion of primary current is returned to the supply line during the “off” period. This results in unproductive power losses in the switching devices and energy recovery diodes. The reverse recovery time of the diode D8 is particularly important because during the turn-on transient, current will flow from D7 into the output inductor L1, and also into the cathode of D8 during it reverse recovery period. This will reflect through to the primary switches as a current overshoot during the turn-on transient [8].

The operation of this welding machine has been described in some detail in order to highlight the importance of the transformer leakage inductance and need for fast recovery diodes.

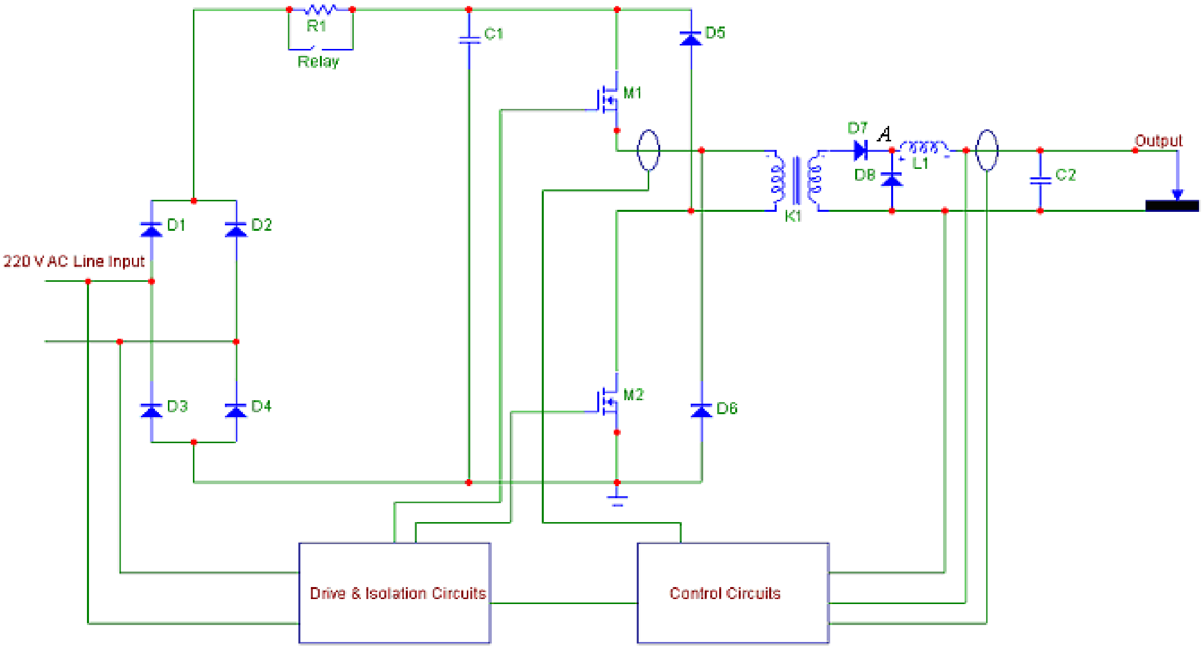

Figure 1. Schematic diagram of the welding machine.

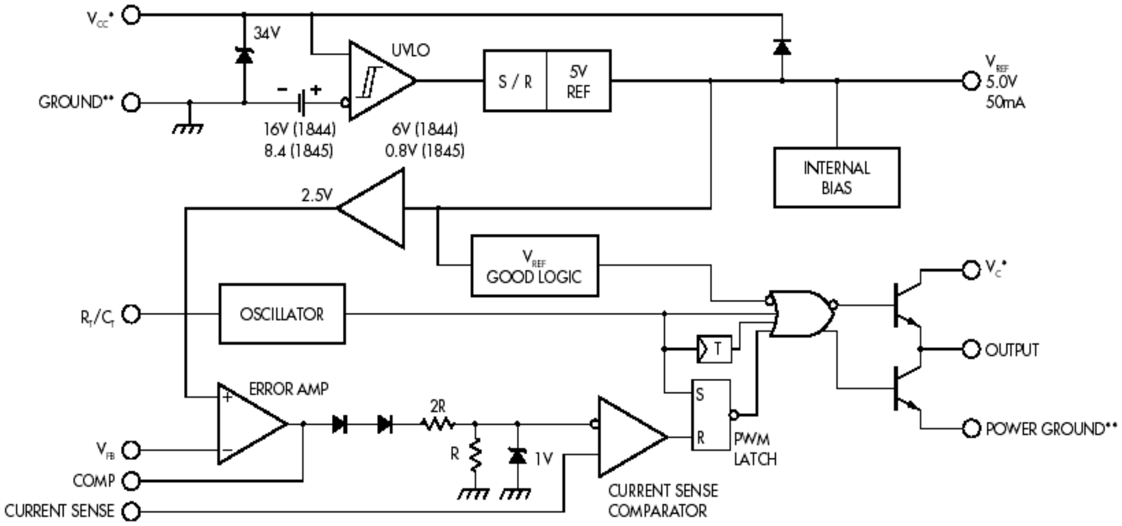

Figure 2. Block diagram of the current mode PWM controller.

These effects become particularly important for high-frequency operation, where the advantages of power MOSFETs are better utilized [9].

It should be remembered that the leakage inductance is not solely within the transformer itself; it is made up of all the external circuitry. The various current loops should be maintained at the minimum inductance by using short, thick wiring, which should be twisted where possible or run as tightly coupled pairs [10].

The energy recovery diodes D5 and D6 should be fast high-voltage types, and low-ESR capacitor should be fitted across the supply lines as close as possible to the switching elements. The ESR and ESL of the output capacitor C2 are not so critically important to the function of the converter, since this capacitor is isolated from the power switches by the inductor L1. The main function of C2 is to reduce output ripple voltages and provide some energy storage. It is often cost effective to use an additional LC filter to reduce noise, so as to avoid the use of expensive low–ESR electrolytic capacitors in this position [11]. A block diagram of the welding machine is shown in Fig. 3. Also, implementation of the welding machine block diagram is shown in Fig. 4.

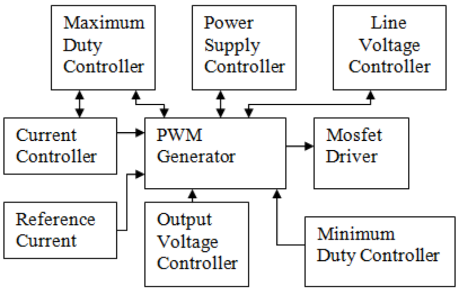

Figure 3. Block diagram of the welding machine

Figure 4. Implementation of the welding machine

V. CONCLUSIONS

The welding machine rating values are: Nominal power P_N=3kW, maximum output current I_0=120A, under no-load output voltage V_0=75V, under load output voltage V_0=24V AC input voltage 220V, 50Hz.

Welding process starts-up to the welding current level by using manual reference potentiometer. The switching frequency is 100 kHz. The two types of control are imposed successively by a pulsed signal. Excellent performance is obtained. In this application both pulse to pulse current control and current control are applied. The former is used for controlling maximum current level: the latter is used for average welding current level. Current feedback from the current transformer is used to limit load current and also to stop PWM generator. Duty cycle generally varies between 40% and 45% values, which are very close to50% of duty cycle. Current Mode PWM inverter welding machines are able to change from current control to voltage control and vice-versa. In this application only the current control is applied. As welding machines are mostly connected to a low voltage network, their current harmonics cause harmonic voltage drops across the network impedance, which results in distorted main voltages. Output welding voltage is also controlled. Power supply controller is made to prevent MOSFETs’ driving with low voltage. It cuts feeding to the PWM generator. One percent of duty cycle value is an important limit value for minimum duty cycle controller. Since rising and falling time values of the MOSFETs become shorter than the duty cycle period, MOSFETs start to turn off action before they can complete turn-on transition. Hence, MOSFETs are prohibited from working in a semi-conduction position. Otherwise MOSFETs could be faulted though under no load. MOSFETs have been saved from these problems by using a minimum duty cycle controller unit. Furthermore, there are no overheating problems for MOSFETs because a cooling fan has been working during the whole welding time. To limit output voltage level up to 78V with the welding machine’s output voltage controller, output current level pulls down to zero. MOSFET drivers are isolated with opto-coupler.

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REFERENCES

[1] L. Malesani, P. Mattavelli, L Rossetto, and P Tenti, “Electronic welder with high-frequency resonant inverter,” in *Proc. IAS*, 1993, pp. 1073-1080.

[2] D. Zhongyi, “Dynamic analysis of arc welding inverter,” *Electric Welding Machine*, vol. 27, no. 4, pp. 7-10, 1997.

[3] Z. Zhimming and Z. Renhao, “High-speed dynamic control for inverter type arc welding power source,” *Electric Welding Machine*, vol. 29, no. 4, pp. 6-9, 1999.

[4] Z. Jinhong, L. Wenlin, and S. Yaowu, “Large signal analysis of arc welding power supply based on Matlab modelling and simulation,” in *Proc. World Congress on Intelligent Control and Automation*, June 28-July 2, 2000, pp. 2567-2569.

[5] Y. M. Chae, Y. Jang, M. Jovanovic, G. J. Suek, and G. H. Choe, “A novel mixed current and voltage control scheme for inverter arc welding machines,” in *Proc. Sixteenth Annual IEEE Applied Power Electronics Conference and Exposition*, 2001, pp. 308-313.

[6] A. Qamaruzzaman, P. Purwadi, and A. Dahono, “A DC high-current low-voltage power generating system,” in *Proc. International Conference on Power System Technology*, October 13-17, 2002, pp. 737-739.

[7] P. P. Cancelliere, V. D. Colli, R. D. Stefano, and G. Tomassi, “A comparative analysis of 4KW PSBs for welding machine,” in *Proc. Fifth International Conference on Power Electronics and Drive Systems*, Nov. 17-20, 2003, pp. 1471-1475.

[8] P. Vieira, J. Pinto, J. A. C. Bolhosa, and D. M. Pereira, “Mathematical modelling and digital control for power supplies of current pulsed for welding machine,” in *Proc. European Conference on Power Electronics and Applications*, Sep. 11-14, 2005, pp. 1-8.

[9] K. Morimoto, D. Toshimitsu, H. Manabe, N. A. Ahmed, L. Hyun-Woo, and M. Nakaoka, “Advanced high power DC-DC converter using novel type half-bridge soft switching PWM inverter with high frequency transformer for arc welder,” in *Proc. International Conference on Power Electronics and Drives Systems*, Jan. 16-18, 2005, pp. 113-118.

[10] J. M. Wang, S. T. Wu, S. C. Yen, and H. J. Chiu, “A simple inverter for arc-welding machines with current doubler rectifier,” *IEEE Transactions on Industrial Electronics*, vol. 58, no. 11, pp. 5278-5281, 2011.

[11] J. M. Wang and S. T. Wu, “A novel inverter for arc welding machines,” *IEEE Transactions on Industrial Electronics*, vol. 62, no. 3, pp. 1431-1439, 2015.

Yasar Birbir received B.S degree from Gazi University, M.S and PhD. from Marmara University. He attended World Bank Industrial Training Project at Indiana and Purdue Universities from 1989 to 1990. He had worked as a visiting research scientist for fifteen months at Drexel University Electrical and Computer Engineering Department from 1992 to 1993. Currently he has been working as a Professor at Technology Faculty in department of Electrical Engineering . He teaches undergraduate and graduate courses in Power Electronics Courses and Electrical Machinery Drives. His current interests beside power electronic converters and drivers, electromagnetic filtering process in the industry and the application of electric currents and electric field effects for sterilization of different microorganisms. Yasar Birbir is an expert on inactivation of archaea and hide bacteria using different electric current applications in leather industry. He has published 20 research articles, presented 33 oral and poster presentations. He has graduated 12 master and two doctorate students and completed 8 scientific projects.