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Operation of a Fuzzy Controlled Half-Bridge DC-Converter as a Welding Current-Source

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Abstrak

Sebuah sumber arus mesin las terkendali logika Fuzi (FCWM) diperkenalkan dalam makalah ini, dan kinerja metode kendali baru ini kemudian dibeberkan. Pengendali Fuzi ini diterapkan pada mesin las untuk memperbaiki beberapa masalah pada proses pengelasan. Pengendali cerdas baru ini menjamin arus konstan selama pengelasan untuk meningkatkan kualitas pengelasan. Ini juga menyediakan beberapa fitur seperti fungsi start-cepat dan anti-macet, dan mode siaga untuk penghematan energi. Efektivitas mesin las cerdas ini dibuktikan dengan hasil eksperimen dan uji tahan lama. Hasil penelitian menunjukkan bahwa FCWM yang dirancang dapat digunakan dalam industri pengelasan bergerak.

Kata kunci: *Welding Machine- Fuzzy Controller-Inverter- Half Bridge*

Abstract

A new Fuzzy controlled welding machine (FCWM) current source is introduced in this paper and the results of the new control method are explained. The Fuzzy controller is applied to the welding machine to improve some problems of welding process. The new intelligent controller guaranties a constant current during welding to improve welding quality. It also provides some features such as hot-start and anti-stuck function and a standby mode for energy saving. The effectiveness of this intelligent welding machine was proven by the experimental results and durable test. The results show that designed FCWM can be used in mobile welding industries.

Keywords: *Welding Machine- Fuzzy Controller-Inverter- Half Bridge*

1. Introduction

The arc welding process consists of heating the metal surfaces of the parts to be joined to their plastic Temperature through passage of high AC or DC electric current. The electric arc (that is discharge into a gas) is ignition between the electrode and the pieces at low voltage drops (10-40 V) at high currents (5-2000 A) [1].The manual-metal arc welding with consumable electrodes (sticks) form approximately 30% of all welding systems [1]. The manual welding machines use the high frequency inverters to provide high capacity currents during operation. The inverter operation frequency is between 20-100 kHz through the use of semiconductors devices with power performances (MOSFET and IGBT transistors) [1]. In this paper a Half Bridge high frequency inverter is used to provide an appropriate current on welding point.

The conventional analog welding machine generates the steady PWM for driving IGBT of its inverter and controls the output welding current by turning on or off of IGBT switches [4]. So it can not regulate well the quality of welding current to track the setting welding Current [2],[3]. In The other control method, the output welding current controlled by changing the duty cycle of PWM. The changes Based on the error between the values of feedback output welding current and the setting current applied to a fuzzy controller. The requirements for a good DC-arc welding machine can be explained as the following: Firstly, an output welding current easily achieves the setting welding current at first welding. Secondly, the output welding current of an electric arc must be maintained constant during the welding process [2]. In this paper we use a fuzzy controller to change the duty cycle of PWM system. The Fuzzy controller will adjust the $e \rightarrow 0$ as $t \rightarrow \infty$. Also by using a Hot-Start function the output current of Fuzzy controlled welding machine (FCWM) easily achieves the setting current at welding start of state. So the electric arc

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of FCWM easily creates and maintains. By adjusting the value of the Hot-Start volume, the FCWM can increase the initial setting current from %20 to %100 bigger than the setting welding current at start. Then the initial setting current is decreased to the setting welding current according to exponential curve.

2. Structure of FCWM

The overall structure of FCWM is illustrated in Figure 1. The AC input voltage rectified by input AC/DC rectifier and applied to high frequency inverter. The transistors S3 and S4 are commanded alternatively a semi period. The voltage drops on capacitors C is equal with 1/2Vdc and connects alternatively to primary winding of transformer via switching transistors in different polarities. At The secondary winding of high frequency transformer the square wave high frequency voltage is rectified, filtered and applied to the welding sticks. A control circuit is used to control the output current of welding machine. The Fuzzy Logic Control (FLC) neither requires a precise mathematical modeling of the system nor complex computations [5]-[8]. This control technique relies on the human capability to understand systems' behavior, and is based on qualitative control rules. Thus, control design is simple, since it is only based on linguistic rules.

This approach lies on the basic physical properties of the systems and it is potentially able to extend control capability even to those operating conditions where linear control techniques fail [5],[9]. As illustrated in Figure 1. The fuzzy controller provides a reference signal, which is applied to a standard PWM modulator. The PWM duty-cycle is proportional to the reference signal and consequently the duty cycle of semiconductor switches and output current changes according to Fuzzy reference signal. The structure of fuzzy controller is explained in the next section.

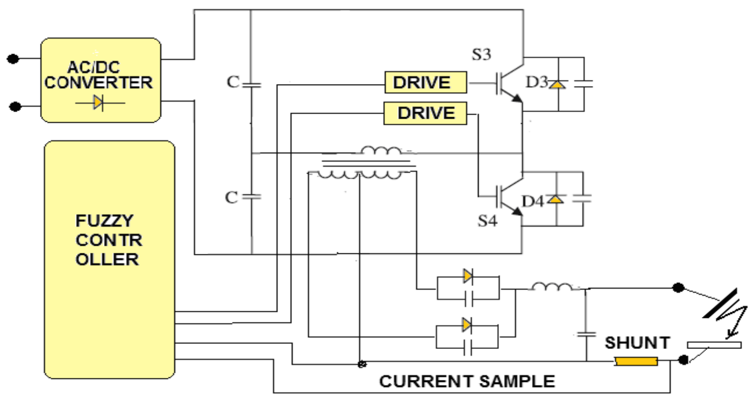


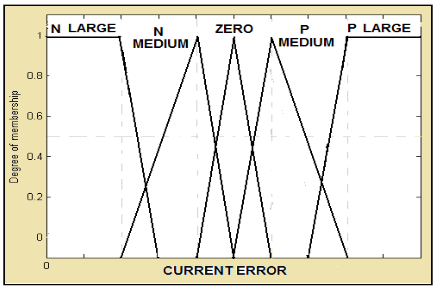
Figure 1. Overall scheme of FCWM

2.1. Structure of Fuzzy Controller

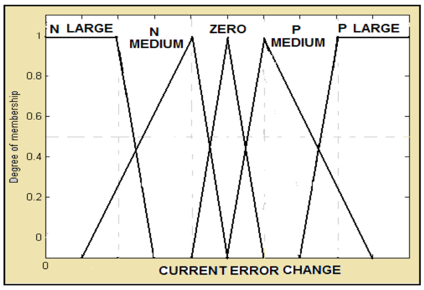
The first important step in the fuzzy controller design is selection of the input and output variables. In this project, the inverter output current is selected as input variable whereas the only output variable is inverter output voltage. Different part of fuzzy controller such as selection of membership functions, Fuzzifier, Inference method and Defuzzifier are explained in the next sections.

2.2. Selection of Membership Functions

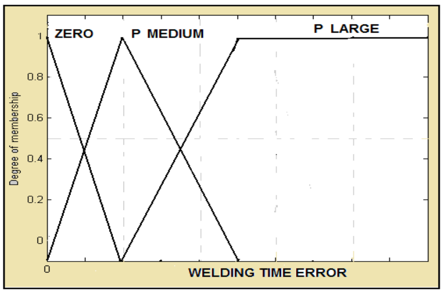
Fuzzy sets must be defined for each input and output variable. As shown in Figure 2, five fuzzy subsets PL (Positive Large), PM (Positive Medium), ZE (Zero), NL (Negative Large), NM (Negative Medium) have been chosen for current error and current error change as input variables. Also three fuzzy subsets (ZE, PM, PL), have been selected for the welding time variable. For the output variable five fuzzy subsets have been used (PL, PM, ZE, NM, NB), in order to smooth the control action. As shown in Figure. 2, triangular and trapezoidal shapes have been adopted for the membership functions; the value of each input and output variable is normalized in [-1,1] by using suitable scale factors.



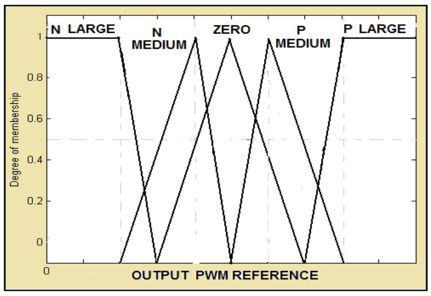
a. current error membership functions



b. Current error change membership functions



c. Welding time membership function



d. Membership function of reference output

Figure. 2. Membership functions of input and output variables

2.3. Derivation of Control Rules

Fuzzy control rules are obtained from the analysis of the system behavior. In their formulation it must be considered that using appropriate control rules depending on the operating conditions can greatly improve the inverter performances in terms of dynamic response and robustness [10]. Three input variable selected for fuzzy system to control the output current in different circumstances according to equations (1), (2), and (3). Current error (e_I), which is difference between output current and reference current defined by operator. Current error changes (Δe_I) which is the difference between errors since T=K to T=K-1. The welding time duration (ΔT_W) is the third variable calculated by microcontroller and is used to change the duty cycle of switching devices.

$$e_I(K) = I_O(K) - I_{REF}(K) \quad (1)$$

$$\Delta e_I(K) = e_I(K) - e_I(K-1) \quad (2)$$

$$\Delta T_W(K) = T(K) - T(0) \quad (3)$$

For instance, when the output current is much higher than of the set point current (PL), the error change is high (PL) and the welding time error is medium (PM), the output duty cycle must be reduced strongly (NL) in order to output current approach to set point as soon as possible. Secondly, when inverter current error (e_I) approaches zero (ZE), error change (NM) is decreasing lowly and welding time error is medium (PM) then the output duty cycle change should be the lowest (ZE). The selected control rules are described hereafter. These rules can obtain in a table to brief and are presented here:

If ΔT_W *is (ZE) ,then* Δ*U is (PL)*

If e_I *is (NL) and* Δe_I *is (NL) and* ΔT_W *is (PM), then* Δ*U is (PL)*

If e_I *is (NL) and* Δe_I *is (NM) and* ΔT_W *is (PM) ,then* Δ*U is (PL)*

If e_I *is (NL) and* Δe_I *is (ZE) and* ΔT_W *is (PM) ,then* Δ*U is (PL)*

If e_I *is (NM) and* Δe_I *is (ZE) and* ΔT_W *is (PM), then* Δ*U is (PM)*

If e_I *is (NM) and* Δe_I *is (PM) and* ΔT_W *is (PM) ,then* Δ*U is (ZE)*

If e_I *is (ZE) and* Δe_I *is (ZE) and* ΔT_W *is (PL), then* Δ*U is (ZE)*

If e_I *is (PM) and* Δe_I *is (PL) and* ΔT_W *is (PM) ,then* Δ*U is (NL)*

If e_I *is (PL) and* Δe_I *is (PL) and* ΔT_W *is (PM) ,then* Δ*U is (NL)*

If e_I *is (ZE) and* Δe_I *is (PM) and* ΔT_W *is (PM) ,then* Δ*U is (NM)*

If e_I *is (PM) and* Δe_I *is (ZE) and* ΔT_W *is (PM) ,then* Δ*U is (NM)*

If e_I *is (PM) and* Δe_I *is (PL) and* ΔT_W *is (PL) ,then* Δ*U is (NL)*

In design of FLC parameters, there are no precise criteria to select gains, fuzzy set characteristics and fuzzy algorithm complexity. Only general guidelines for the design of the FLC can therefore be given. For the purpose of generality, the universe of discourse for each fuzzy variable was normalized between [-1;1]. The scale factors greatly affects the bandwidth and the overall performance of the controller and some heuristic tuning can be used in order to improve charger performances.

2.4. Fuzzy Algorithm and Software Features

There are numbers of ways on how to define fuzzy implications, the sentences connective *and, else* used for the fuzzy rules and the inference mechanism; criteria and properties can be found in the literature [6,7]. If The fuzzification process is done through fuzzy singletons and the Mamdani's Min-Max fuzzy implication is used as inference method the output inferred value, $f(X)$ as a function of input variables X_i calculated as below nonlinear function (4).

$$f(X) = \frac{\sum_{i=1}^{M} Y^{-1}\left(\min_{i=1}^{n} \mu_{A_1^l}(X_i)\right)}{\sum_{i=1}^{M}\left(\min_{i=1}^{n} \mu_{A_1^l}(X_i)\right)} \tag{4}$$

In our project, according to the above criteria

$$\mu_l = \min\{\mu_l(e_I), \mu_l(\Delta e_I), \mu_l(\Delta T_W)\} \tag{5}$$

Lastly, the Center of Area method was selected for the defuzzification process. With these choices the inferred value of ΔU_{pwm} the control action in correspondence to the value (e_I), (Δe_I) and (ΔT_W) is:

$$\Delta U_{pwm} = \frac{\sum_{l=1}^{m} \mu_l(pwm)\, U_l}{\sum_{l=1}^{m} U_l} \tag{6}$$

Where U_l is singleton value of fuzzy output variable using the l-th rule and $\mu_l(pwm)$ is the degree of Fulfillment of the l-th rule.

3. Control implementation and Practical Results

In Figure 3, the overall software program is presented in a flowchart. The scheme includes two basic sections: a software preprocessing section, where controller inputs are evaluated, Fuzzy inference process is performed and output variable is computed. The other section includes data acquisition process and hardware commands.

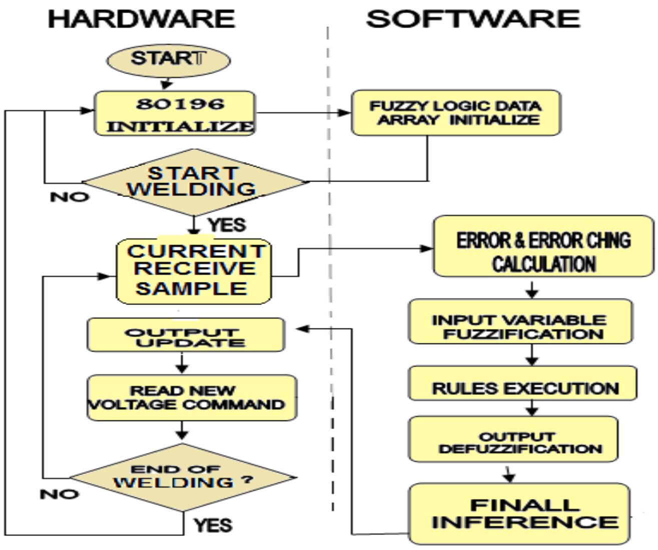


Figure 3. Fuzzy control software flowchart

The above mentioned sections are stored in the memory of a *80C196* Microcontroller. Figure 4 shows the overall hardware blocks of FCWM designed.

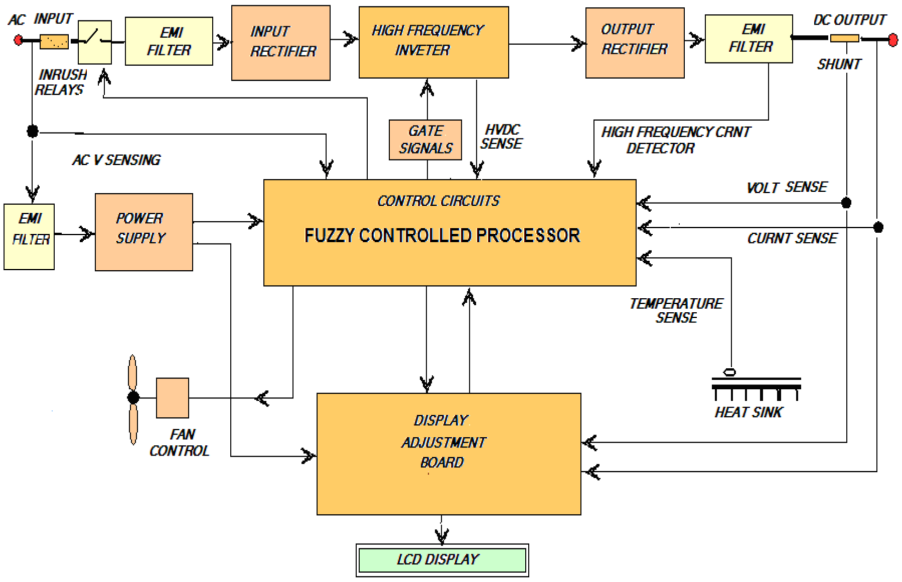


Figure 4. Functional blocks of FCWM hardware

Several functional hardware features designed for FCWM to make it applicable in practical welding experiences. These features increase stability and safety of operation.

The reference signal as a nonlinear function of the input variables is calculated implemented by the microcontroller on base of a fuzzy inference process. The output reference signal used to change the duty cycle of a couple of complementary PWM modulated signals. The PWM signals applied to semiconductor switches to control output welding current .the output current variation was verified by a HALF- BRIDGE inverter topology. Figure 5 shows the schematic of power circuits.

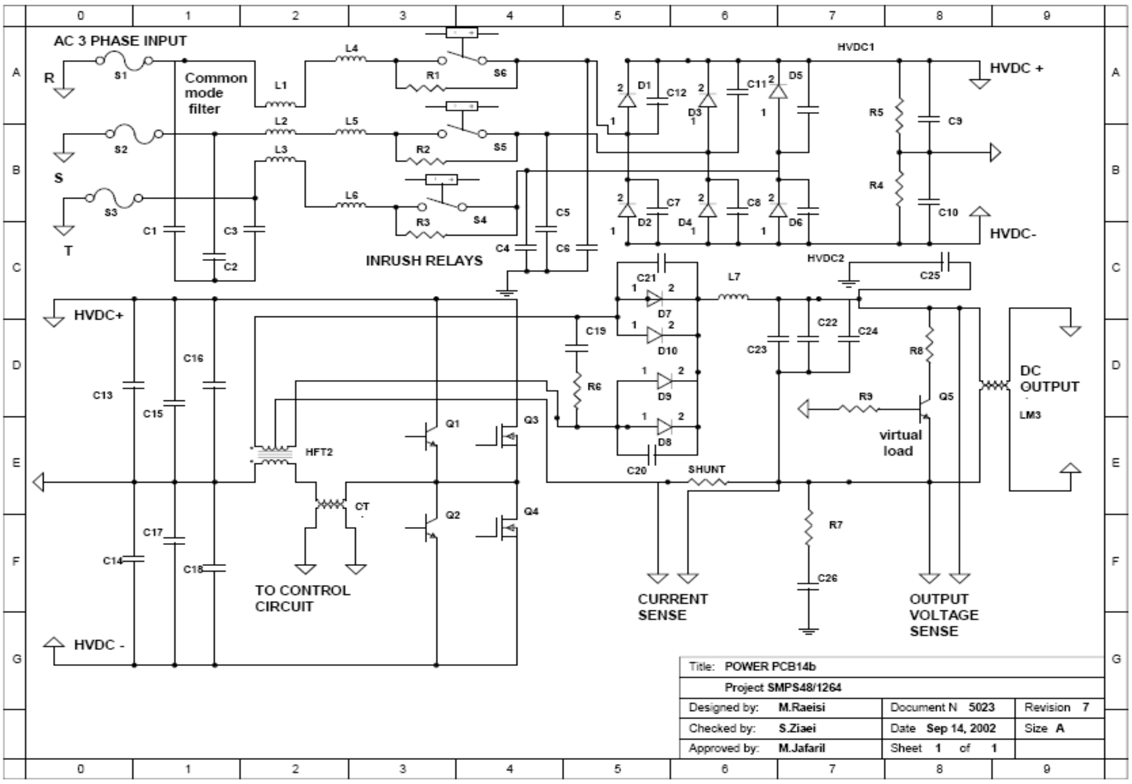


Figure 5. Schematic of power circuits of FCWM

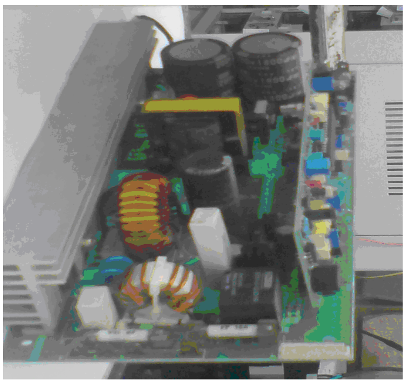


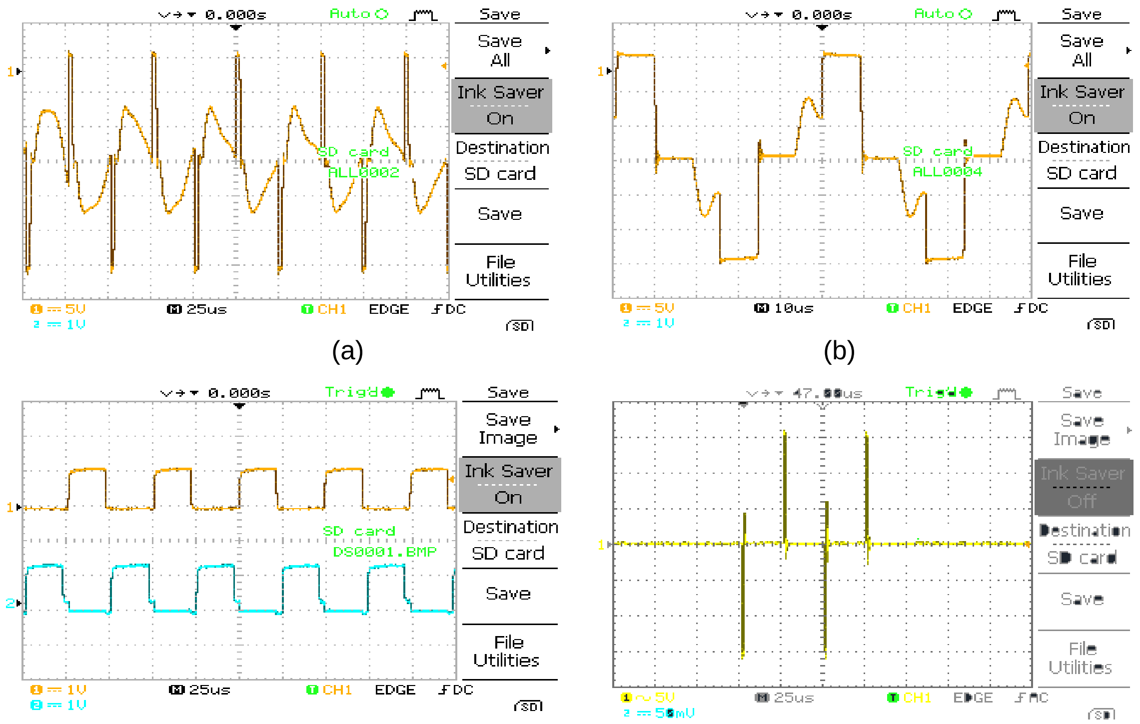
Figure 6. Implementation of FCWM

This intelligent welding machine was made in Research and Development Department of EMC Company and experimentally tested. Figure 6 shows the hardware implemented system.

4. Experimental Results

The designed FCWM experimentally tested in several welding practices .the output current is set at 80A and the value of hot-start volume is set 40%. A data acquisition system is used to register output current and voltage variations via a sampling circuit. The waveforms of V_{CE} on IGBT switches and gate driving signals observed via oscilloscope and showed in Figure 7 for both of active and inactive welding times. The recorded samples of output welding current and voltage variations received and drew by EXCELL software. The sampling time is 10ms.The drawn graphs show that output current rapidly raised about %140 of adjusted current at first welding because of the hot-start operation. The output current reaches to the set point current approximately 700ms after start time and remained constant for the next times to provide a uniform and constant welding.

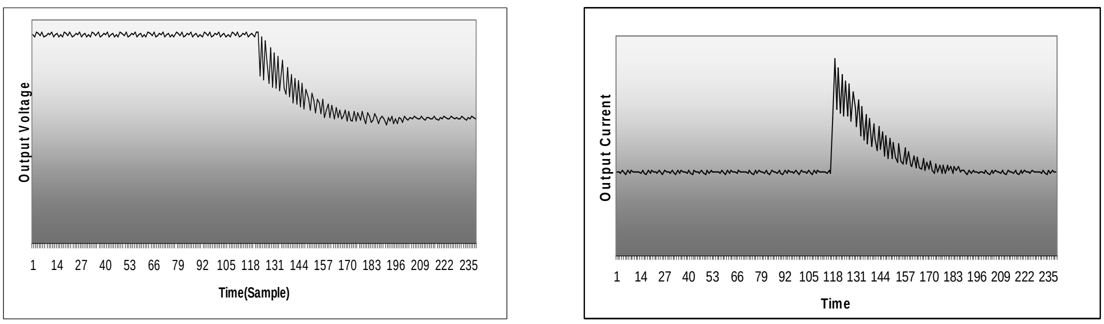
By hot-start function the electric arc is easily made and maintained at first. The current output tracks the setting welding current very well. The recorded data show that the current error is converted to zero about 800 ms after start time.



(a) (b)

(c) (d)

Figure 7. Wave forms of IGBT switches in %10 (a), %50 (b), and No-load (d). Gate driving signals (c)



(a) output voltage variation during welding (b) output current variation during welding

Figure 8.output current and voltage variations in a welding test

5. Conclusions

This paper introduces a new Fuzzy Controlled Welding Machine (FCWM) which improved some problems of traditional systems .this intelligent welding machine increases welding current simultaneously at the start time to provide Hot-start and anti-stuck operation. The designed FCWM has a small size and light weight and save energy in comparison with former systems. A fuzzy controller is applied to the Half-Bridge inverter to control the output welding current. The FCWM increases welding quality, stability and reliability of welding process and can have a great of contribution to the mobile welding industries. The effectiveness of the FCWM was proven by the experimental results.

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