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Current control of welding inverter using 32-bit microcontroller

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***Abstract* — This paper summarizes the elaboration of a master's thesis entitled "Welding Inverter Utilizing a 32-bit Microcontroller," completed during the second winter semester. The present work extends the findings of a previously published article entitled "Welding Inverter Using 32-bit Microcontroller," in which a welding inverter hardware was adapted to incorporate STM32 microcontroller and current mode control. The current paper focuses on the load testing of the inverter and addresses the identified issues. One such issue was mitigated through the integration of a Proportional Integral Derivative (PID) controller, followed by the inclusion of a comfort feature.**

***Keywords* — anti-stick, high power, PID controller, welding inverter**

I. INTRODUCTION

The paper titled "Welding Inverter Using 32-bit Microcontroller" delineated the requisite procedures for integrating a welding inverter with a 32-bit microcontroller. The resultant inverter incorporated current mode control and a touch screen, which enabled the user to adjust the current level as per their requirement. Although the inverter has not been utilized for welding purposes as yet, the study asserted that the inverter is prepared to supply current and withstand testing with greater loads [1].

The present paper provides a comprehensive overview of the subsequent advancements made to the proposed welding inverter. The primary objectives and anticipated outcomes remained consistent throughout the development process, which involved the integration of hardware and software, and troubleshooting of issues that emerged during the course of development.

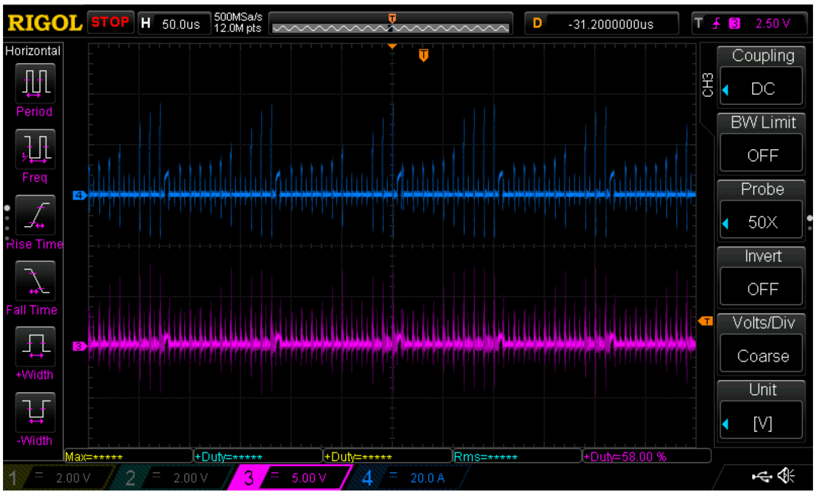
II. LOAD TESTING

As mentioned, the inverter was operational and capable of delivering current. However, it was promptly realized that conducting welding as a means of load testing the inverter in a laboratory setting was unsuitable owing to problems related to repeatability and consistency. Considering the inverter's capacity to generate several kilowatts of power, it was challenging to obtain DC bench loads or power resistors, which are relatively scarce or expensive.

Instead, a lead-acid battery cell was utilized, which can absorb current during its charging phase. This approach has demonstrated to be a feasible method for bench-testing high-current power supplies. By employing a battery cell with a nominal voltage of 12 V, a current sink in the range of tens of amperes was achieved. Subsequently, during further testing, the use of two of these batteries in parallel enabled the attainment of a load exhibiting a current in the range of hundreds of amperes, and a voltage range between 14 to 18.5 volts, contingent on the state of charge.

The testing of the inverter under this load yielded promising outcomes with the provision of gradually escalating currents. The current mode control mechanism performed as intended, and the average current output level could be set and regulated with ease.

At precisely the 50 A level, a distinct sizzling sound emanated from the inverter. Since the main switching frequency, which is 100 kHz, is beyond the range of human hearing, it was evident that the inverter was oscillating at a lower frequency. An oscilloscopic measurement of the current through the primary winding of the transformer was conducted by measuring 20 to 30 switching periods, as opposed to the conventional 3 or 4 periods. The obtained results, illustrated in Fig. 1, depict that the primary transformer current (probe nr. 4) and, consequently, the output current oscillates every 5 to 6 switching periods with an inconsistent duty cycle. This issue was not evident during simulation and manifested only during hardware testing. The resulting oscillation led to electromagnetic compatibility (EMC) concerns with surrounding electrical appliances, and testing was halted to prevent any possible damage. This outcome suggested that the current mode control was insufficient to provide a consistent current output at higher power levels, and a different approach was deemed necessary.



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Max=*****
+Duty=*****
+Duty=*****
Rms=*****
+Duty=58.00 %
1 = 2.00 V
2 = 2.00 V
3 = 5.00 V
4 = 20.0 A

Fig. 1 Current oscillation

III. PID CONTROLLER

As the current mode control did not offer a stable current output, the implementation of a controller became necessary. A controller, being an integral component of a control circuit, generates a modulated output value that is dependent on an error value determined by a regulation rule. Various controllers can be acquired based on the mathematical expression of the regulation rule, with the most common being proportional, integral, and derivative controllers. A PID controller, as shown in Fig. 2, integrates the functionality of all three basic controllers and is widely used in various industries due to its simplicity, robustness, and effectiveness. It can be digitally executed using microcontroller code, making it a suitable option for this project. [2].

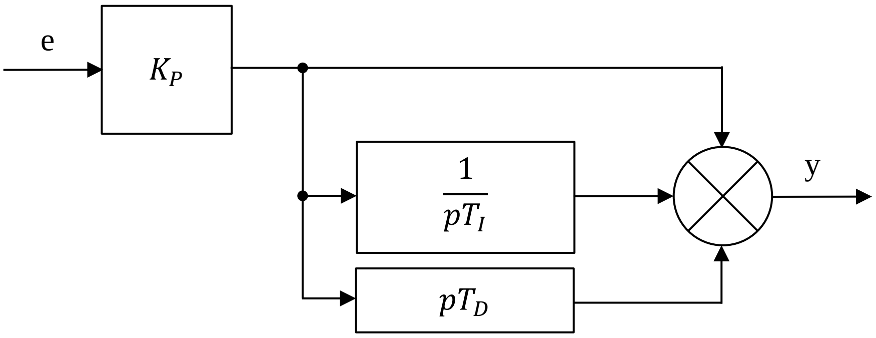

Fig. 2 PID controller schematic

In this scenario, the output current of the inverter should serve as the measured process variable, while the duty cycle used to drive the DC/DC converter should be the generated value to achieve a constant current capability. However, this approach lacks protection against sudden short circuits of the inverter, which is common during welding when the positive and negative terminals are temporarily touched to create an arc. The PID controller may initiate the arc with full duty cycle until the necessary changes are made, potentially leading to overcurrent damage to the electronics. To prevent such damage, overcurrent protection is required in this setup. The current mode control, which has the ability to respond to sudden load changes such as a short circuit, can be repurposed with minimal modifications to serve as overcurrent protection.

In this scenario, the use of a PID controller is proposed to control the output current while the current mode control mechanism is utilized for overcurrent protection. During the development of this system, it is crucial to prioritize overcurrent protection over the controller. To achieve this, the PID controller is programmed into the "while(1)" loop of the microcontroller, with the output of the PID controller directly changing the duty cycle of the control signals through CCR1 and CCR4 registers of Timer1 that drive the DC/DC converter. In case of overcurrent, the existing current feedback and comparator COMP2 are used with direct connection to Timer1 through the OCRef_Clear function, which can turn off the output signal. This allows the comparator to always limit the output current, regardless of what the processor is doing.

To obtain the error value for the PID, current feedback is necessary. The current feedback is obtained using an off-the-shelf component - a current transducer, preferably a hall effect one, as the signal sent to the microcontroller needs to be galvanically isolated. The LEM HAS 200-S hall effect current transducer was chosen for its 0-200 A RMS measurement current capability and quick response time with a delay of less than 3 µs. The measured current is scaled to an output voltage range of 0-5 V, which is later scaled to 0-3.3 V for the microcontroller using a voltage divider. The transducer requires a ±15 V power supply, which is achieved using a small DC/DC converter by TracoPower [4].

The analog signal from the current feedback is connected to a 12-bit A/D converter, ADC2, which is configured to direct-memory-access. This feature allows the periphery to write or read data to and from memory without using the processor's computing power. ADC2 is set for continuous conversion, where each conversion result is written to an array in memory, which is accessed by the PID controller loop [3].

To test this new control strategy, software changes were made as described, and hardware changes to the control PCB were required. Instead of modifying the existing PCB, a new one was made to accommodate the new current feedback. The resulting PCB was created as per Fig. 3.

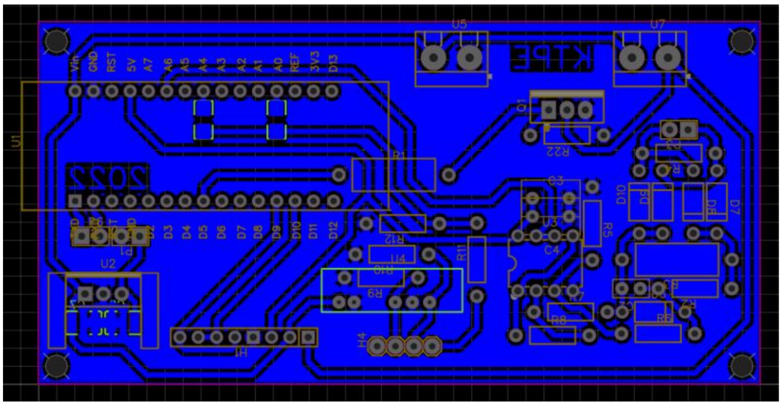

Fig. 3 PCB with current feedback

IV. Testing the PID and welding

The developed controller underwent load testing following the procedure described in the second chapter. Initially, tests were performed to fine-tune the software, ensure proper hardware functioning, and adjust PID parameters. After the initial debugging, the inverter was able to deliver the same power as before, approximately 500 W, without any issues. The PID controller was visibly adjusting the duty cycle of the converter to maintain a constant current at the output, even with various load voltages, and no oscillations, as previously observed, were present with this controller. Electromagnetic interference issues were also resolved. During the short circuit test, the overcurrent protection mechanism functioned as expected. Moreover, a stable output current as low as 5 A was achieved, which served as a test of the PID controller's capability, despite being useless for welding.

Continuing with testing, a desired current was set in 10 A steps. The inverter sourced a current of 163.7 A at 18.5 V, providing 3028.45 W of power, which corresponded to the desired current of 160 A. A 2% error was observed, but it was within the tolerance of the current transducer and noticeable only for currents above 100 A. Further testing was halted due to safety concerns associated with lead-acid batteries as a load.

Numerous additional tests were performed to verify the inverter's full functionality. These tests were deemed successful, indicating that the developed electrical hardware and the PID controller can source high power controllably and repeatedly. It was concluded that the inverter could be used for welding purposes. Several welding joints were prepared, using the Tungsten Inert Gas (TIG) welding method because it provides the same electrical characteristics regarding constant current requirements, and can even be used with small currents (less than 10 A). Additionally, TIG welding does not require filler material, allows for the arc to stay burning without torch movement, and does not generate sparks. As a result, the author selected this method for testing purposes. The results of the welding tests were successful, as seen in Fig. 4, with a current of 60-70 A used for this material thickness.

Fig. 4 Welded joints

To initiate the welding arc, a momentary short circuit is required. However, there are instances when the electrode fuses with the workpiece and creates a continuous short circuit. This occurrence can be problematic, but commercially available inverters address this issue by implementing an "anti-stick" feature. This feature automatically shuts off the current flow after detecting a stuck electrode, thereby preventing further damage to the electrode and the workpiece.

V. ANTI-STICK FEATURE

Incorporating anti-stick functionality would significantly improve the user experience. In order to implement this feature, it is necessary for the microcontroller to determine whether the electrode is stuck, which can be achieved by monitoring the output voltage. Since a stuck electrode creates a short circuit, the output voltage will be close to 0 V but not precisely zero due to current flow through the welding cables, which creates a voltage drop. As a result, a threshold voltage must be established. To accomplish this, a measurement was taken on a commercially available inverter, the Kitin 150 by Kühtreiber, which identifies voltages below 7 V as short circuits and triggers the anti-stick circuit. This value was used as the initial threshold, which can be adjusted in software at a later time.

To provide voltage feedback, an optocoupler 4N25 was utilized, as it provides galvanic insulation. Its output was scaled to 3.3 V to match the microcontroller's pins. To activate the anti-stick functionality, a comparator COMP4 was employed in conjunction with a DAC2 D/A converter to establish the threshold value. Since a temporary short circuit is inherent in welding, the microcontroller must activate the anti-stick feature only after the short has persisted for a significant period. To accomplish this, Timer16 was employed to implement a one-second delay. When a short circuit is detected, the COM4 interrupt activates Timer16. After one second has elapsed, a timer period elapsed callback is triggered. At this point, the comparator determines whether a short circuit is still present. If it is, the current is reduced to a minimum. Similarly, the short circuit must be eliminated for at least one second before the current is restored.

As described, the software modification was successfully completed, but the hardware modification necessitated the production of a new PCB, which incorporated the voltage feedback feature. This new PCB was designed to fit within the old PCB's footprint, as shown in Fig. 5.

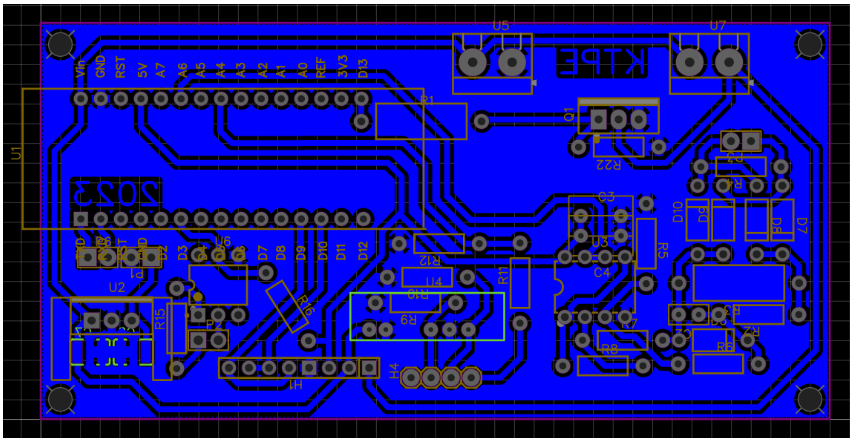

Fig. 5 PCB with voltage feedback

After debugging and software tweaking, it was found that the anti-stick feature was effective and worked as expected on the bench. However, during welding, the inverter produces pulsed voltage instead of smooth DC voltage, which triggered the comparator. To address this issue, an R-C low pass filter was retrofitted to smooth out the voltage feedback. This modification successfully mitigated the issue.

VI. CONCLUSION

A novel current controlling method has been incorporated into the welding inverter, thereby expanding its operating current range to facilitate the welding of steel. Consequently, the inverter is rendered safe to use and does not risk any adverse impact on the neighboring electronic circuits. Future tests are warranted to gauge the inverter's efficiency. The voltage feedback system warrants refinement as occasional interruption of the comparator can impede the PID loop's efficacy.

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