

Interleaved Parallel Two-Transistor Forward Converters for Pulsed MIG Welding

Linbing Wang^{1, a, *}, Xiaoya Yin^{1, b}, Youxuan Xiao^{1, c}, Jin Yan^{1, d}, Bin Lian^{2, e}

¹ School of Aeronautics, Northwestern Polytechnical University, Xian, China

² Dongguan Sanhang Civilmilitary Integration Innovation Institute, Guangdong, Dongguan, China.

*,^a Corresponding author e-mail: wlb@nwpu.edu.cn, ^b 644868415@qq.com,

^c 1243046586@qq.com, ^d 575801490@qq.com, ^e 1533754302@qq.com

Abstract. In this paper, a pulsed MIG welding power system based on the interleaved parallel two-transistor forward converter is studied. The hardware structure principle diagram and overall control scheme of the system are analyzed. This paper focuses on the analysis of the small-signal model of the main circuit, and establishes the transfer function of the arc-length loop and the current loop respectively, and designs a double closed-loop controller. Experiments were carried out according to the paper's scheme. The experimental waveforms prove that the power system scheme of this paper is correct and feasible.

1. Introduction

The two-transistor forward converter overcomes the shortcomings of the high voltage stress of the switching transistor in the forward converter, and can ensure the reliable magnetic reset of the transformer without using a special reset circuit. In addition, it does not have the problem of straight-through of the bridge arm, and the reliability is high, which is one of the most significant advantages of such a converter. Thus, the two-transistor forward converter becomes one of the most widely used topologies in power converters [1-4].

This paper uses a forward converter that is staggered in parallel at the freewheeling diode, and increases the capacity of the converter and reduces the power of each converter by paralleling in this paper, the interleaving technique is used to increase the equivalent frequency of the converter, reducing the volume of the filter [5] and the ripple of the output current.

2. System description

As shown in Figure 1, the main circuit of the welder includes two parallel two-transistor forward converters that share a freewheeling diode at the output. Because the transformer energy storage has a release path, the two-transistor forward converter does not require additional magnetic reset measures. The output circuit has two rectifier diodes D5, D6 and a freewheeling diode D7. L and C are the output filter inductor and the output filter capacitor, respectively. The primary side and the secondary side turn ratio of the transformer is $n=N1:N2$.

The system will adopt current and voltage double closed loop control. The outer ring is an arc voltage loop (also known as an arc long loop) which is to maintain the stability of the arc length. And the inner loop



is a current loop, which is used to achieve a constant current during the pulse droplet transfer. The system collects two parameters of arc voltage and welding current through Hall sensor in real time, and performs feedback adjustment to achieve fast response, high control precision and high stability of welding.

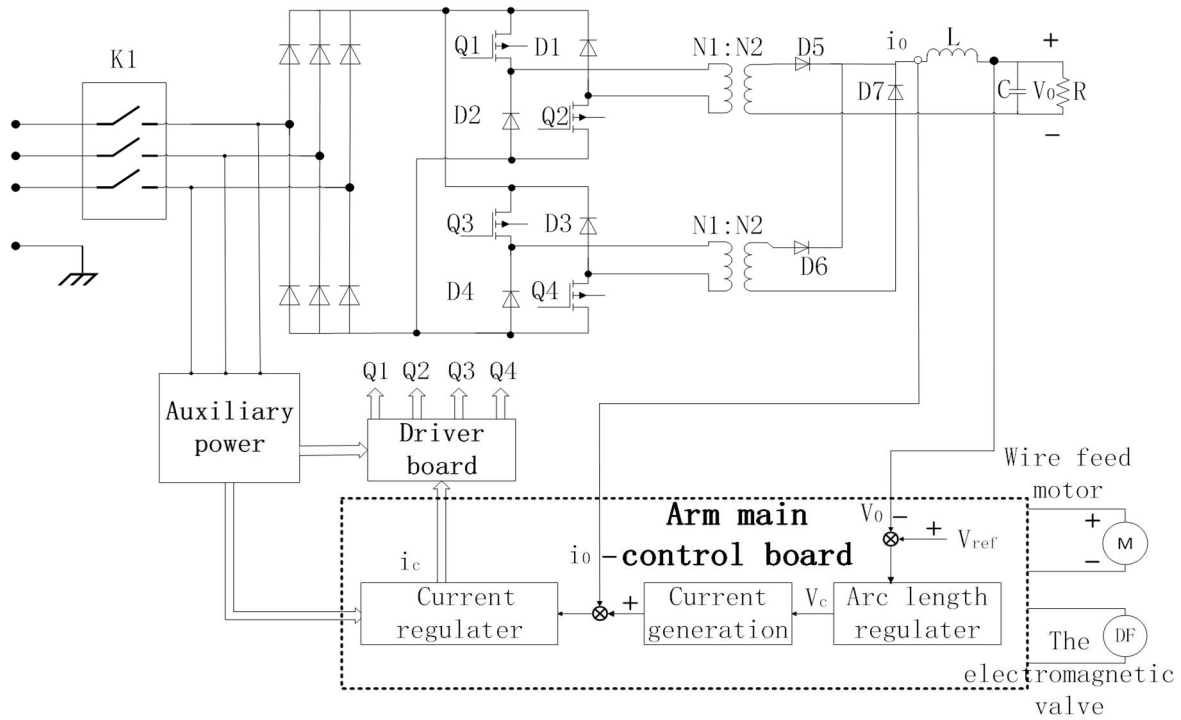


Figure 1. System control diagram

3. Small Signal Model Analysis and Transfer Function

3.1. Small Signal Modeling of Interleaved Double-Tap Forward Converters

Create a small signal model. It is assumed that the input voltage v_i is equal to the sum of the steady state value V_i and the AC small signal component \hat{v}_i , and the duty ratio d is equal to the sum of the steady state value D and the AC small signal component \hat{d} .

$$v_i = V_i + \hat{v}_i \quad (1)$$

$$d = D + \hat{d} \quad (2)$$

In response to these inputs, the output voltage v_o and the output current i_o will be equal to the sum of the corresponding steady state value and the AC small signal component, respectively:

$$v_o = V_o + \hat{v}_o \quad (3)$$

$$i_o = I_o + \hat{i}_o \quad (4)$$

Assuming that the magnitude of the AC change is less than the DC static value, the nonlinear model can be linearized around the static value [9]. The small-signal model of the interleaved parallel two-transistor forward converter is derived, as shown in Figure 2. Where R is the equivalent load of the welder and L is the filter inductor.

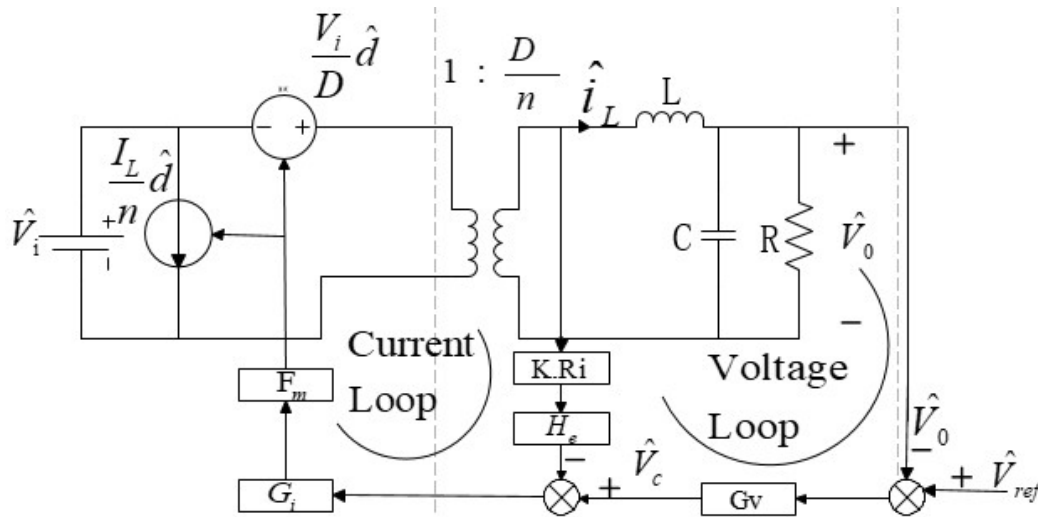


Figure 2. Small Signal Model and Control Block Diagram for Interleaved Parallel Dual-Tap Forward Converters

$$\left(\hat{v}_i + \frac{V_i}{D} \hat{d}\right) \frac{n}{D} = \hat{v}_0 + \hat{i}_L sL \quad (5)$$

$$\hat{i}_L = \frac{\hat{v}_0}{R} (1 + RsC) \quad (6)$$

The converter contains two independent AC inputs: Control Input \hat{d} and Linear Input \hat{v}_i . The AC output variable \hat{v}_o can represent the superposition of the output items produced by these two inputs:

$$\hat{v}_o(s) = G_{vd}(s) \hat{d}(s) + G_{vg}(s) \hat{v}_i(s) \quad (7)$$

Where transfer functions $G_{vd}(s)$ and $G_{vg}(s)$ can be defined as:

$$G_{vd}(s) = \left. \frac{\hat{v}_o(s)}{\hat{d}(s)} \right|_{\hat{v}_i=0} \quad (8)$$

$$G_{vg}(s) = \left. \frac{\hat{v}_o(s)}{\hat{v}_i(s)} \right|_{\hat{d}=0} \quad (9)$$

According to (8) and (9), $G_{vd}(s)$ and $G_{vg}(s)$ can be expressed as:

$$G_{vd}(s) = \frac{2V_i/n}{s^2 LC + s \frac{L}{R} + 1} \quad (10)$$

$$G_{vg}(s) = \frac{2D/n}{s^2 LC + s \frac{L}{R} + 1} \quad (11)$$

3.2. Control strategy

The transfer function $He(s)$ of the sampling model in current mode control is [10-12]:

$$He(s) \approx 1 - \frac{T_s}{2} S + \left(\frac{T_s}{2} \right)^2 S^2 \quad (12)$$

The modulator gain transfer function is [13] [14]:

$$F_m = \frac{\hat{d}}{\hat{v}_c} = \frac{1}{V_m} \quad (13)$$

The transfer function of the error amplifier is:

$$G_v(s) = k_{vp} + \frac{k_{vi}}{s} \quad (14)$$

$$G_i(s) = k_{ip} + \frac{k_{ii}}{s} \quad (15)$$

The open loop transfer function of the current loop is:

$$Ti = F4 \cdot Fm \cdot Fi \cdot G \quad (16)$$

Among them

$$F4 = \frac{nVi}{R} \frac{1 + S \cdot (C \cdot R + Rc \cdot C)}{S^2 \cdot L \cdot C (1 + \frac{Rc}{R}) + S(\frac{L}{R} + C \cdot Rc) + 1} \quad (17)$$

$$Fi = n \cdot K \cdot Ri \cdot He \quad (18)$$

The voltage loop open loop transfer function is:

$$T_v = G_v \cdot A_c \quad (19)$$

The control-to-output transfer function is:

$$A_c = \frac{\hat{V}_c}{\hat{V}_o} = \frac{F_2 \cdot F_m \cdot G_i}{1 + T_i} \quad (20)$$

$$F_2 = n \cdot V_i \frac{1 + S \cdot C \cdot R_c}{S^2 \cdot L \cdot C (1 + \frac{R_c}{R}) + S(\frac{L}{R} + C \cdot R_c) + 1} \quad (21)$$

After the above model is established, the control parameters of the system can be designed in combination with the main circuit parameters.

4. Experimental results

Table 1. Technical parameters

<i>name</i>	<i>value</i>
Input voltage V_i	Three phase 380V/50Hz
Rated input power f	13kVA
Maximum output current I_o	350A
Output no-load voltage V_o	75V
Switching frequency f_s	32KHz

Table 1 lists the electrical parameters of the experimental system.

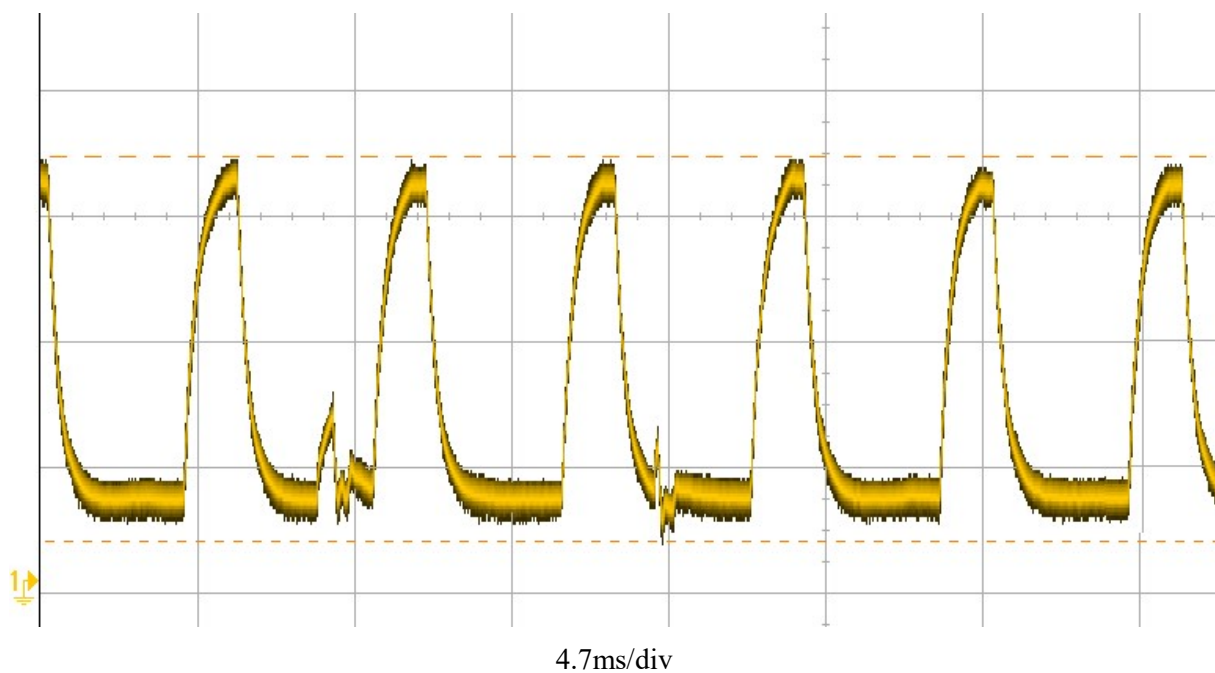


Figure 3. Output current waveform

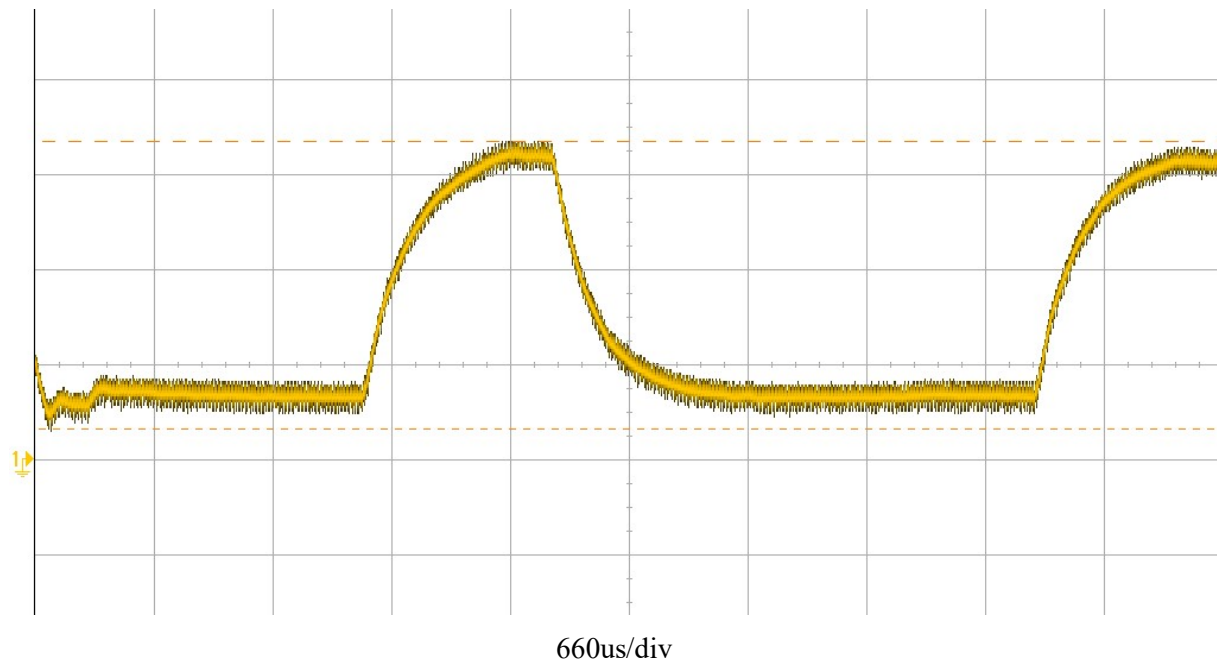


Figure 4. Output current waveform

Figure 3 shows the output current pulse waveform of the welder. It can be seen that the output current waveform of the staggered parallel double-switch forward converter is stable. The time unit of the horizontal axis is 4.7ms/div, and the waveform frequency is 176Hz.

Figure 4 shows an enlarged pulse waveform diagram containing a complete cycle to facilitate observation and calculation of specific values. The time unit of the horizontal axis is 660us/div, and the frequency of the current waveform is 176.7 Hz. In order to facilitate a clear observation of the waveform, figure 4 amplifies the waveform of figure 3.

5. Conclusion

This paper studies a pulsed MIG welding power system. The main circuit adopts a parallel two-tube forward converter, and establishes a small signal model of the main circuit and a closed-loop control model to build an experimental prototype. The current waveform of the prototype experiment is stable and reliable, which proves that the scheme is correct and feasible. The main welding circuit of this paper has the natural advantage of preventing the straight-through of the bridge arm and is suitable for use in high-reliability welding systems.

Acknowledgments

This work was financially supported by Dongguan Science and Technology Equipment Project (KZ2017-03) and Shenzhen Science and Technology Project (CKCY2016082411090757).

References

- [1] Shen Y Q, Yao G, Xiang-Ning H E. A Parallel-parallel Combined Two Transistor Forward Converter with Coupled Inductor[J]. Power Electronics, 2005.
- [2] Michael T.Zhang,Milan M.Jovanovic,Fred C.Y.Lee,Analysis and evaluation of interleaving techniques in forward converters [J].IEEE Transaction on Power Electronics. 1998, pp: 690-698.
- [3] Zhang F H, Wang H Z, Yan Y G. THE PUSH-PULL FORWARD RECTIFIER AND ITS APPLICATION[J]. Proceedings of the Csee, 2004.
- [4] Ayob S M, Azli N A, Salam Z. PWM DC-AC Converter Regulation using a Multi-Loop Single

- Input Fuzzy PI Controller[J]. Journal of Power Electronics, 2009, 9(1):28-41.
- [5] F.H.Khan, L.M.Tolbert, "A Multilevel Modular Capacitor-Clamped DC–DC Converter," IEEE Transactions on Industrial Application, vol. 43, no.6, pp.1628-1638, Nov. 2007
- [6] Deshang Sha, Zhiqiang Guo, XiaoZhong Liao, "Cross-Feedback Output-Current-Sharing Control for Input-Series-Output-Parallel Modular DC–DC Converters," IEEE Transactions on Power Electronics, vol.25, no.11, pp.2762-2771, Nov. 2010.
- [7] Z. Bingul, G.E. Cook, "A real-time prediction model of electrode extension for GMAW," IEEE/ASME Transactions on Mechatronics, vol.11, no.1, pp. 47- 54, Feb. 2006.
- [8] Abraham I.Pressman. Switch supply power design.1998
- [9] Zachariah K S, Madhusudhanan, Vennila M, et al. High power frequency parallel resonance inverter with bridgeless rectifier for induction heating application[C]// International Conference on Electrical, Electronics, and Optimization Techniques. IEEE, 2016:4847-4852.
- [10] Liaw C.M., Chiang S.J., Lai C.Y , et al., "Modeling and Controller Design of a Current-Mode Controlled Converter", Industrial Electronics, IEEE Transactions on, Volume: 41 Issue: 2, April 1994 pp. 231 -24
- [11] Kazimierzuk M.K. , "Transfer Function of Current Modulator in PWM Converters with Current -Mode Control", Circuits and Systems I: Fundamental Theory and Applications, IEEE Transactions on, Volume: 47 Issue: 9, Sept. 2000 pp. 1407 -141
- [12] Raymond B. Ridley, "A New, Continuous-Time Model For Current-Mode Control", Power Electronics, IEEE Transactions on, Volume: 6, Issue: 2, April 1991 pp. 271·280
- [13] Hong-Xue W U, Yang W, Yang S Y. Design of Phase-shifted Full-bridge DC/DC Converter Based on Digital Control with TMS320F28027[J]. Journal of Power Supply, 2012.
- [14] Shibata K, Pham C K. A compact adaptive slope compensation circuit for Current-Mode DC-DC converter[C]// IEEE International Symposium on Circuits and Systems. IEEE, 2010:1651-1654.