IMPLEMENTATION OF A BATTERY-FED SINGLE-PHASE INVERTER FOR A LOW POWER INDUCTION HEATING APPLICATIONS

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Abstract: In low power induction heating applications like brazing or welding of small sections, a low power furnace required. This paper deals with implementation of a proposed power supply fed from a portable battery for such applications. Such furnace used in case of unavailability of electric mains or to avoid flame of an ordinary welding equipment. A prototype of a single-phase Push-Pull inverter implemented and an experimental test is conducted. The results approve the validity of the proposed circuit.

Keywords: Induction Furnace, Brazing, Push-Pull.

1. Introduction

The application of induction heating for brazing of copper tubes for repair may need a self-fed portable device due to unavailability of electricity mains in the sight. This work considers such circumstances, then a portable furnace has to be implemented. Such a source must be of simple and cheap design in order to be of low weight. Also, it must be flexible to be used for brazing of copper pipes. For this purpose, a Push-Pull high frequency single-phase voltage source inverter is intended to feed a parallel tank circuit composed of the induction coil connected in parallel to a low equivalent series resistance (ESR) capacitor as shown in Fig. 1.

The available literature about this subject are patents of such device fed from the mains without design details as well [1, 2, 3]. In [4], Hanan K., study this furnace in details and simulate the proposed furnace using MATLAB Simulink.

Figure 1. The proposed circuit to be implemented

In [4] a 24V battery feeding the Push-Pull inverter of a step-up transformer is proposed and simulated. The simulation results of the circuit shown in Figure. 1 reveals that ($I_2=0.44A$) and a sinusoidal voltage appears across the tank circuit ($V_2=355.24V$), inducing a sinusoidal current in the tank circuit ($I_{tank} = 1131A$). This means that the current ratio (I_r) of the circuit ($I_r = I_{tank}/I_2$) is about (2570). This magnitude of induction coil current is able to generate a sufficient magnetic flux for the welding process by induction.

The objective of this research is to implement a prototype of the controversial circuit proposed by [4] and approve experimentally that the

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conclusions from the simulation results are accurate.

In this work the designed ferrite transformer [5] is wound and the IC (SG 3525 PPSB) is chosen as a PWM drive for the Push-Pull electronic switches [6]. The implemented circuit is tested by applying the output voltage of 150V, 50Hz from the proposed inverter across a tank circuit of (1.54mH) and (0.33 μ F). The obtained results approve the validity of the proposed circuit in [4].

2. Design Implementation

The circuit designed and simulated in [4] consists of two parts, the triggering circuit and the power circuit. The power circuit is well analyzed, while, the triggering circuit has to be discussed in this work. The most important part of the power circuit is the ferrite transformer; hence, the same design steps are implemented, and an EE ferrite core type 0P43515EC wound with the same type and number of primary and secondary windings. The switches are MOSFETs type IRFP250 [7].

The triggering circuit is implemented using a PWM chip type SG 3525 PPSB [8] as a controller for the pulse width of the trigger fed to the MOSFETs. The properties of the IC are as follows:

- Operation voltage of (8.0V-35V).
- Separate Oscillator Sync Pin.
- Input Undervoltage Lockout.
- Adjustable Deadtime Control.
- Oscillator Range of (100Hz-400kHz).

A schematic diagram of the implemented circuit is shown in Figure. 2. Two resistances are added, the first is of 10 Ω connected in series with the battery and the second of 440 Ω is connected in series with the tank circuit. These resistances are added for the sake of protection during the experimental test and to show the current waveforms at these branches of the circuit. Also, a tap of half the output voltage of the transformer secondary is used for testing

only. Fig. 3 show the implemented prototype of Fig. 2.

Figure 2. The implemented circuit.

Figure 3. The implemented Push-Pull circuit

3. Experimental Work and Discussion

The aim of the experiments is to prove the validity of the proposed circuit. Two experiments are conducted, in the first one, the inverter loaded by a 700 Ω pure resistive load, as shown in Fig. 4. The triggering pulses to the gate of the transistors shown in Fig. 5, while Fig. (6-8) show the output voltage, the voltage across the transformer primary, and the battery current consecutively. The load used in [4] is a tank circuit composed of an induction coil of 1 μ H, and 10 μ F capacitor of 400kVAr. The huge current of this circuit must be avoided in this

step. Hence, the tank circuit used in the second experiment instead composed of a (1.54mH) toroidal shape, ferrite core coil (to simulate the induction coil), connected in parallel to a (0.33 μ F, 400kVAr) capacitor.

The following results shown in figures (9-13) are obtained in the lab. The importance of this test is that it proves the ability of the proposed power supply to feed induction furnaces in such applications.

Figure 4. The test with 700 Ω resistive load

Figure 5. The triggering pulses to the gate

Figure 6. The primary voltage waveform

It is clear that the output voltage is a square wave of 150V, 50kHz as shown in Fig. 8, which is half the output voltage of the transformer.

Figure 7. The output voltage waveform

Figure 8. The current from the battery

Figure 9. The voltage waveform across the tank circuit

Figure 10. The voltage across the 440Ω resistor

Figure 11. The secondary output voltage waveform

Figure 12. The voltage across the primary

Figure 13. The voltage across the 5Ω resistance in series with battery

4. Discussion of Results

The experimental results obtained prove the idea adopted for such type of power supplies in induction heating. The results show that the current supplied from the push-pull transformer (I_2) is (1.5mA) while the tank circuit current (I_{tank}) is:

$$I_{tank} = \frac{V_{tank}}{X_c}$$

$V_{tank} \equiv$ The rms value of the voltage across the tank circuit.

$I_{tank} \equiv$ The rms value of the current passing through the tank circuit.

$X_c \equiv$ The capacitive reactance of the parallel capacitance of the tank circuit.

Since

$$X_c = \frac{1}{2\pi f_r C}$$

$f_r \equiv$ The resonance frequency of the tank circuit.

$C \equiv$ The capacitance of the parallel capacitance of the tank circuit.

The resonance frequency (f_r) is 50kHz, and the capacitance=0.33μF

$$X_c = \frac{1}{2\pi \times 50 \times 10^3 \times 0.33 \times 10^{-6}} = 9.646\Omega$$

From the experimental results: $V_{tank_{max}}=150V$, which represents the maximum value of the voltage across the tank circuit shown in Fig. 12. Where,

$$V_{tank} = \frac{V_{tank_{max}}}{\sqrt{2}} = \frac{150}{\sqrt{2}} = 106V$$

$$I_{tank} = \frac{106}{9.646} = 11A$$

The current (I_2) from the ferrite transformer secondary passing through the $440\ \Omega$ resistance (r_s), which is connected in series with the tank circuit can be measured by measuring the effective voltage (V_{r_s}) across (r_s), using a true (rms) voltmeter as follows:

$$I_2 = \frac{V_{r_s}}{r_s} = \frac{0.7}{440} = 1.6\text{mA}$$

Hence, (I_2) represents the current fed by transformer secondary. From the previous calculations the current ratio (I_{ratio}) between the real current and the imaginary current (I_{tank}) of the tank circuit is:

$$I_{ratio} = \frac{I_{tank}}{I_2} = \frac{11}{1.6 \times 10^{-3}} = 6875$$

Since, the apparent power supplied to the tank circuit is equal to the terminal voltage of the transformer secondary multiplied by its output current (I_2), then:

$$P_o = V_{tank} \times I_s = 106 \times 0.0016 = 0.17\text{VA}$$

The transformer output voltage is the same as that of the tank circuit, then the power of the tank circuit is

$$P_{tank} = V_{tank} \times I_{tank} = 106 \times 11 = 1166\text{VA}$$

Hence, these results prove the validity of the theoretical results achieved using MATLAB Simulink by [4], taking into consideration the application of a real brazing load.

5. Conclusions:

This work leads to many conclusions, these are:

- The proposed circuit can be used as a power supply for a portable induction welding machine.
- The tank circuit load is more suitable than the series resonant circuit in that, the series circuit use a step down high frequency ferrite transformer[9], while the tank circuit

feed the induction coil by the reactive power itself. This feature is suitable for a low weight, simple and low-price portable tool. Fig. (14) show the tank capacitor.

Figure 14. The tank capacitor of $0.33\mu\text{F}$

- Since, the required capacitor for the welding machine is of $10\mu\text{F}$ capacity, then this capacitor can be achieved as two capacitors of $5\mu\text{F}$ connected in parallel as that shown in Fig. 15, since each capacitor of mass equal to 600g, then the an 1200g will be the mass of the two capacitors.
- The proposed induction coil for this welding machine will be as predicted by Fig. 16.

Figure 15. The $5\mu\text{F}$ capacitor

- The portable welding machine can be built from two parts, the driving circuit and the tank circuit. These two parts connected by two thin (Litz) wires. This property furnishes a high flexibility for the users during the welding process.

Figure 16. The proposed induction coil for copper tube brazing

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Conflict of interest

The authors of this article acknowledge that the publication of this article cause no conflict of interest to anybody or institution.

References

1. C. H. Henderson. (1968). "*Portable Remote Induction Brazing Station with Flexible Lead*". United States Patent Office No. 3,403,240.
2. John, P. Robert, C. (2006). "*Portable Induction Heating Tool for Soldering Pipes having a U-Shaped Head Portion Comprising an Induction Coil*". European Patent Specification No. 1 725 366 B1.
3. John P. Robert C. (2007). "*Induction Coil Design for Portable Induction Heating Tool*". United State Patent No. 7.202450 B2.
4. Hanan K. Abdulabbas. (2019). "*Design and Analysis of a Push-Pull Inverter for*

Portable Induction Welding Machine Using Battery and PV Power Source". M.Sc. Thesis, University of Technology, Iraq.

5. Wm. T. McLyman, (2004). "*Transformer and Inductor Design Handbook*". Third Edition, Marcel Dekker, Inc.
6. Muhammad H. Rashid, (2007) "*Power Electronics: Circuits, Devices, and Applications*". Third Edition, Prentice-Hall.
7. Keith Billings, Taylor Morey, (2011). "*Switch Mode Power Supply Handbook*". 3rd Edition, McGraw-Hill.
8. Ned Mohan, William P. Robbins, Tore M. Undeland. (2003). "*Power Electronic Converters, Applications, and Design*". 2nd Edition. USA.
9. Mohammad Hameed Khazaal. Isam Mahmood Abdulbaqi, Rabee' Hashim Thejel (2016). "*Modeling, Design and Analysis of an Induction Heating Coil for Brazing Process Using FEM*". Proc. Al-Sadeq International Conference on Multidisciplinary in IT and Communication Science and Applications (AIC-MITCSA). pp. 1-6.