A Series-Resonant Half-Bridge Inverter for Induction-Iron Appliances

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Abstract- This paper presents a series-resonant half-bridge inverter for induction iron appliances. The series-resonant inverter is implemented to provide Zero Current Switching (ZCS) for all the switches at turn off conditions and Zero Voltage Switching (ZVS) at diode turn on. The main features of the proposed inverter are simple PWM control strategy and high efficiency. The operation mode of the inverter will be evaluated corresponding to the duty cycle of the switch. The experimental results verify the advantages of the proposed topology.

Index Terms- ZVS, ZCS, induction iron, half-bridge inverter, resonant

I. INTRODUCTION

INDUCTION heating system can apply for many things such as induction hardening, induction melting, induction cooking, etc [1]. One thing that is no paper to propose for induction heating systems is induction iron. Therefore, this is the first time to propose the induction iron appliance. Induction iron is a low-power induction-heating systems with a maximum output power usually less than 1.5-kW per load. An induction iron appliance is basically made up of a flat-type inductor coil, with insulator, in which the iron tray to be heated is placed. Between the iron tray and the coil, an insulator is placed in Fig. 1. The heat is generated at the iron tray’s bottom due to eddy currents and hysteresis losses. These induced currents are caused by an alternating magnetic field generated by a medium frequency (20–100 kHz) current through the coil. Iron tray-inductor coupling is usually modeled as the series connection of an inductor and a resistor, based on the transformer analogy. The values of the equivalent inductance and resistance depend on the operating frequency and the required maximum power.

Fig. 1 Iron tray with Coil

An arrangement of an induction iron is shown in Fig. 2. An induction iron takes the energy from the mains voltage, which is rectified by a bridge of diodes. In this paper, a bus filter is designed to allow a large voltage ripple to obtain the high input power factor. Then, the inverter topology supplies the high-frequency ripple current to the induction coil. The main inverter topologies used in induction heating system are the resonant inverters, including full-bridge, half-bridge and single-switch inverters. In this case, induction iron appliance including is possible to use a half-bridge inverter as shown in Fig. 3.

II. CHOICE OF CONVERTER

The half-bridge, series resonant converters were selected above the single-switch topologies due to the following reasons [3]:
- The voltage across the semiconductors is clamped. Even though two switches are needed, at least half the voltage blocking capability is required.
- Due to switching is done at a duty ratio of 50%, feedback is not needed.
Anti-parallel composite-switches must be used, as shown in Fig. 3, consisting of a singular-switch (S) and an anti-parallel diode (D). Isolated gate bipolar transistors (IGBTs) are shown because they are well suited for this medium frequency application. Although an isolated gate drive is needed, an opto-isolator can be used due to the 50% duty ratio. The
switching power loss in the semiconductors could be a disadvantage and is investigated.

The are generally two possible switching schemes for this converter to obtain the desired output power control without varying the input voltage, i.e. load commutation and forced commutation. In this paper, the load commutation should be applied.

Load Commutation
A typical iCS waveform is shown in Fig. 4. The power is decreased by decreasing switching frequency (f_s) below the resonant frequency (f_r) where

\[ f_s = \sqrt{1/LC_1} \]

Giving the following advantages and disadvantages:

- No turn-off power loss for the singular-switches (ZCS) and no turn-off power loss for the anti-parallel diodes (ZVS) as shown in Fig.4.
- Maximum power is obtained at the upper limit of the switching frequency.
- Turn-on power loss for the singular-switches and turn-off power loss and reverse recovery current for the anti-parallel diodes.

To be easily operated, the load commutated converter was applied. The elimination of the reverse recovery current of the diodes [3,4]and the maximum power was obtained at the upper point of the switching frequency range, usually about 30 kHz. The following changes were made to the converters described by:

- The resonant capacitors \((C_1+C_2) \parallel C)\) are used, as shown in Fig. 3, so that current is drawn from the supply during each half cycle of the switching period, enhancing the power factor.

### III. Operation Principles

Fig. 5 shows possible current paths of the inverter output voltage \(V_{AB}\) and load current \(i_L\) which are only one cycle (see Fig. 2 or Fig. 6). Also, the operation waveforms are shown in Fig 6. To simplify it, the following assumptions are provided:

- The resonant capacitors are ideal
- Inductance L is working coil and work piece
- Resistance R is work piece
- all devices are no losses.
There are 4 switching modes in a switching period as described in the following.

Mode 1: \((t_0-t_1)\) [Fig. 5(a)]: Switch \(S_1\) conducts the load current \(i_L\). The output voltage across the load (inverter output voltage) is \(V_i/2\). The zero current of switch \(S_1\) is zero at turn off. In this mode, the zero current switch (ZCS) of switch \(S_1\) is achieved.

Mode 2: \((t_1-t_2)\) [Fig. 5(b)]: Switch \(S_1\) is off. The voltage across \(S_1\) is zero to prepare the diode \(D_1\) going to a zero voltage switch (ZVS) at turn on. The diode \(D_1\) conducts the load current \(i_L\) in the opposite direction of mode 1. The output voltage across the load is still equal to \(V_i/2\).

Mode 3: \((t_2-t_3)\) [Fig. 5(c)]: Diode \(D_1\) is off. Switch \(S_2\) conducts the same side of load current \(i_L\) and \(S_2\) achieves the ZCS condition. The output voltage across the load is \(-V_i/2\). When the switch conducts, the voltage across switch \(S_2\) is zero.

Mode 4: \((t_3-t_4)\) [Fig. 5(d)]: Switch \(S_2\) is off. The voltage across \(S_2\) is zero to prepare the diode \(D_2\) going to a zero voltage switch (ZVS) at turn on. The diode \(D_2\) conducts the load current \(i_L\) in the opposite direction of mode 3. The output voltage across the load is still equal to \(-V_i/2\).

The next cycle will be repeated mode 1 and so on.

IV. EXPERIMENTAL RESULTS

The experimental results are done for the main components as given below:

\[ C_1=C_2=12 \mu F; \quad C = 0.8 \mu F, \quad L = 35.62 \mu H, \quad R = 26 \text{ mohm}, \]

Maximum input voltage \(V_i = 310 \text{ V}\).

This inverter can be operated under soft switching conditions as shown in Fig. 4, and its output power cannot be regulated continuously due to the fact that the input voltage \((V_i)\) has a high ripple (as shown in Fig.7) following by the ac input voltage. However, the duty cycle control for switches is fixed. The duty cycle \(D\) is equal to 0.35. The results from each voltage and current of switch per cycle are shown in Fig.8 that is indicated as the soft switching (ZVS and ZCS like Fig. 4). The characteristics of voltage and current waveform of the previous cycle is look like the same as the next cycle, but the amplitude of voltage and current is different. Therefore, the inverter output voltage and load current waveform are shown in Fig. 9. That is indicated that switch is operated as the load commutation.
In addition, the experiment shows the heat from the iron sheet that is compound of the iron. Fig.10 shows the average absorbed temperature results from the thick of the iron sheet. The more thickness of iron sheet had, the more time for getting high temperature had. Moreover, Fig. 11 shows the average emitted temperature results from the thickness of the iron sheet. The more thickness of iron sheet had, the more time for reducing high temperature to low temperature had. In this case, the upper limit of temperature is 90 °C while lower limit of temperature is 30 °C. To use appropriately in this research, 4-mm thickness of iron sheet was used.

Furthermore, the test of heat, which is from iron sheet, is compared between the induction iron and ordinary electric iron. The right hand side of Fig. 12 shows the distributed-

Fig. 9 The inverter output voltage ($v_{AB}$) (square wave) and load current ($i_L$) (almost sine wave).

In Fig. 13, the output power of ordinary electric iron is compared with that of induction iron. When the output power from induction iron is tested at 385 watts, the output power from the ordinary electric iron is 880 watts, the induction iron can save more energy per hour. The energy per hour from ordinary electric iron is 0.117 kW/h, but the induction iron is 0.092 kW/h. The efficiency of induction iron is 92% as shown in Fig. 14.

Fig. 10 The average temperature absorbed from the thick of iron sheet.

Fig. 11 The average temperature emitted from the thick of iron sheet.

Fig. 12 Distributed temperature over the iron sheet from thermo-scan.

Fig. 13 Output power of both irons.

Fig. 14 Efficiency of induction iron.
V. CONCLUSION

In this paper the operation principle of the prototype induction iron is introduced together with the switching frequency lower than resonant frequency, power desired and ZCS and ZVS algorithm incorporated in it. Its performance characteristics are verified by the experimental results for a prototype induction iron rated at 385 W. The induction iron is designed to replace ordinary electric iron. The prototype has been developed and the performance is good. It can provide the heat like ordinary electric iron, it can reduced to 1/2 of the power for the same amount of heating capability.

REFERENCES


