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# Self-Oscillated Induction Heater for Absorption Cooler

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***Abstract*—Self oscillated resonant inverters have the advantages of low cost and simplicity. DC-AC power conversion can be achieved without using special drivers. In this study, self oscillated half bridge series resonant inverter topology is designed and applied to induction heater as a boiler part of home type absorption cooler system. The designed system has rapid and stable heating/cooling response compared to conventional resistance heated system. Self oscillated resonant inverter can achieve soft switching and maintain resonant tracking with simple and cheap drive circuit during all heating period.**

***Index Terms*—Self oscillated inverter, induction heater, half bridge, zero voltage switching, absorption cooler.**

## I. INTRODUCTION

Since self oscillating circuits have the advantages of simplicity, reliability and low cost [1], [2] they are used in high frequency applications such as electronic ballasts [3]–[5], dc-dc converters [6] and induction heating systems [7]–[9].

Varying magnetic field in a metal due to induced eddy current generates heat [10]. In literature, this is called induction heating [11]. Metallic work piece is placed inside an induction coil which creates time-varying magnetic fields at high frequencies. Induction heating is an appropriate method for heating metals, surface hardening, melting, brazing etc. [12]. It is also a fast, effective and efficient heating technique for pipeline fluid heating systems [13].

Contactless heating [14] is another important future of induction heating systems to heat flammable liquids or gasses.

During the induction heating process, the variations in the load parameters are important because output power and switching losses are related with equivalent load parameters those are affected by the temperature and position of the metallic work piece. Therefore, it is necessary to keep the output current and output voltage in phase for retaining soft switching conditions over the heating period.

It is possible to control the resonant converters by using phase locked loop (PLL) integrated circuit [15], [16] or microprocessor based controller [14], [17] to overcome the problem as mentioned. However their control systems require auxiliary power supply, driver IC, hall-effect sensor and isolation circuit.

Among the many different types of inverter topologies, the half bridge series resonant inverter is the most widely used one for domestic induction heaters due to its simplicity, no electrical requirements for its components and cost effectiveness [10].

In this study, self oscillating control technique is applied to an induction heater driven by a half bridge series resonant inverter without using any active control device. MOSFETs are used in the inverter as power switches controlled by the secondary of the current transformer. 75W self oscillating induction heater is designed and implemented on a boiler part of absorption cooler. For the absorption cooler required heat is generated by simple and low cost induction heating system. When performances of the induction heating and the resistance heating systems for absorption cooler are compared it is clear that the induction heating has main advantage of rapid temperature response. The designed induction heated absorption cooler has 12 minutes better start up cooling characteristic than the resistance heated cooler.

## II. SELF OSCILLATED INDUCTION HEATER

### A. Series Resonant Half Bridge Inverter

Figure 1 shows the induction heating self oscillated voltage fed half bridge series resonant inverter as heat source of absorption cooler. The current through the power switches decreases as the load current decreases in the series resonant inverter, so it is suitable for low current applications [18].

The inverter consists of two power switches (*M1*, *M2*), a resonant capacitor (*C*), loaded induction coil equivalent resistance (*R*) and inductance (*L*). The loaded induction coil with resonant capacitor constitutes series resonant tank.

Self oscillating driver simply includes a current transformer (*CT*), four zener diodes ($D_{Z1}$-$D_{Z4}$), a soft switching inductor ($L_{ss}$), a series triggering resistance ($R_s$) and start/stop buttons. The drive circuit does not need any

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auxiliary power supply or driver IC.

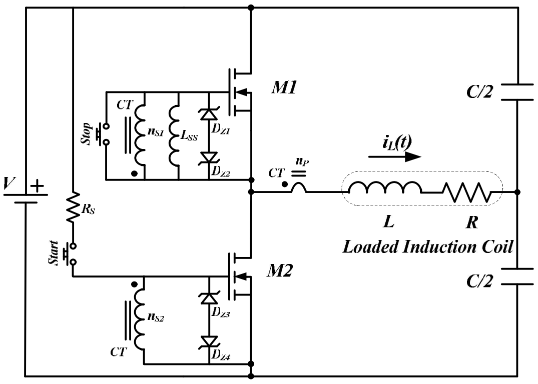



Fig. 1. Self oscillating half bridge resonant inverter.

DC supply voltage ($V$) is converted to high frequency AC current by alternately switching of the MOSFETs that are driven by complementary polarity secondary windings ($n_{s1}$, $n_{s2}$) of the current transformer. The primary winding of the current transformer is connected in series with resonant tank in order to control MOSFETs. Hence a relation between inverter switching frequency ($f_s$) and resonant tank frequency ($f_r$) is obtained:

$$\omega_r = 1/\sqrt{LC} = 2\pi f_r, \tag{1}$$

$$\omega_s = 2\pi f_s. \tag{2}$$

In the half bridge series resonant inverter the load current will be nearly sinusoidal for high quality factor ($Q$) applications

$$Q = \omega_r L/R. \tag{3}$$

When the switching frequency is near the resonant frequency, the load current can be defined as follows [19]:

$$i_L(t) = I_m \sin(\omega_s t - \Phi), \tag{4}$$

$$I_m = \frac{2V}{\pi R\sqrt{1+Q^2\left(\omega_n - \frac{1}{\omega_n}\right)^2}}, \tag{5}$$

$$\Phi = \tan^{-1}[Q(\omega_n - 1/\omega_n)], \tag{6}$$

$$\omega_n = \omega_s/\omega_r. \tag{7}$$

Power of the induction heater can be calculated from (8):

$$P = \left(I_m/\sqrt{2}\right)^2 R. \tag{8}$$

In the half bridge series resonant inverter the load current must lag from the applied voltage at resonant network to achieve soft switching [19], [20]. If the inverter operates above the resonant frequency, switches are turned on with zero voltage (ZVS) [15], [19], [20]. Hence switching losses can be reduced during the heating period.

*B. Self Oscillating Drive Circuit*

In recent studies, the linear model of the current transformer was used to explain the driving circuit principle of electronic ballast [1], [3], [4], [20], [21]. According to linear model, primary side of current transformer is presented by a sinusoidal current source ($i_s$) in parallel with linear magnetizing inductance ($L_m$) as shown in Figure 2. Sinusoidal feedback current of the resonant tank is converted to a MOSFET driving voltage with the current transformer [20].

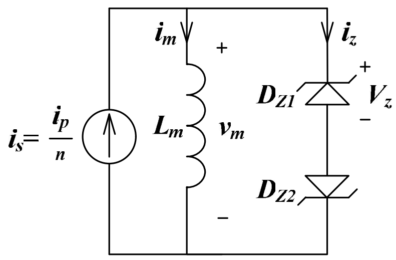



Fig. 2. Linear model of the current transformer.

Figure 3 shows theoretical current and voltage waveforms of the driver equivalent circuit. Whenever zener current ($i_z$) crosses zero, the polarity of gate voltage reverses [21]. In other words direction of the zener current defines the polarity of $V_g$. The zener current has also relation with $i_m$ and $i_s$ (KCL)

$$i_s = i_m + i_z. \tag{9}$$

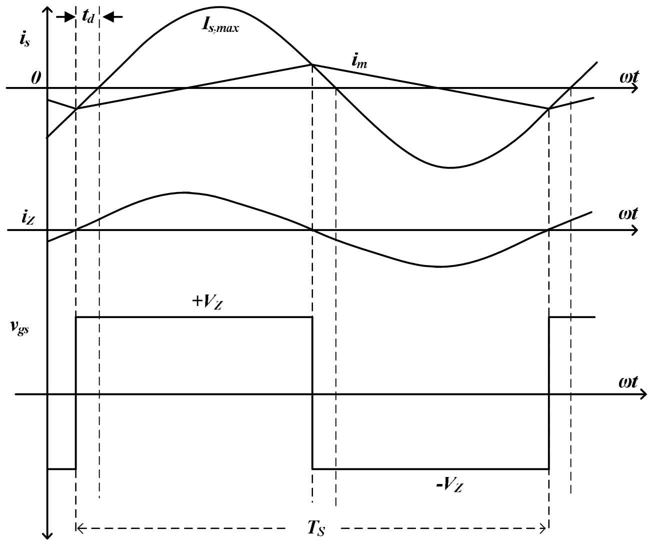



Fig. 3. Theoretical waveforms of the driver circuit.

When the driving transformer is assumed as ideal, magnetizing current linearly changes. The peak value of the magnetizing current ($I_{m,max}$) can be calculated by using (10):

$$I_{m,max} = V_z/(4 f_s L_m), \tag{10}$$

$$L_m = L_s = n^2 A_L, \tag{11}$$

where $A_L$ is inductance factor of the core, n is secondary turn number of current transformer which has turn ratio 1:$n_{s1}$:$n_{s2}$ ($n_{s1} = n_{s2} = n$).

As shown in Fig. 3 when the peak value of magnetizing current increases, phase difference between the driving voltage and resonant current increases. So the resonant current lags from the driving voltage and switching frequency becomes bigger than the resonant frequency.

To obtain the square wave switching voltage, $I_{m,max}$ must not exceed the maximum value of secondary current ($I_{s,max}$). So there is a critical magnetizing inductance ($L_{mcr}$) to keep the $I_{m,max}$ below $I_{s,max}$

$$L_{mcr} = V_z/(2 f s I_{s,max}). \tag{12}$$

$L_m$ must be bigger than $L_{mcr}$ for defined core type and turn ratio to achieve desired switching waveform.

### C. Effect of MOSFET Gate Capacitance

One of the other parameter that affects the switching frequency in self oscillating inverters where the MOSFET power switches are used is the MOSFET gate to source capacitance ($C_{gs}$). The driving voltage leads the resonant current and the switching frequency becomes smaller than the resonant frequency by the effect of $C_{gs}$.

To achieve the desired switching frequency for soft switching, effect of $C_{gs}$ must be suppressed. In the self oscillating inverter switching frequency can be increased by adding a parallel coil ($L_{ss}$) to the secondary of the current transformer [1]. Hence, the decreasing effect of $C_{gs}$ on the frequency is removed and soft switching conditions can be maintained. Additional $L_{ss}$ allows an increase in the slope of the magnetizing current and then as a result switching frequency increases.

## III. ABSORPTION COOLER

Absorption cooler is a cooling technique without using any mechanical compressor and uses a heat source to circulate the volatile liquid in the cooling cycle. A simplified cooling cycle of the absorption cooler is shown in Fig. 4.

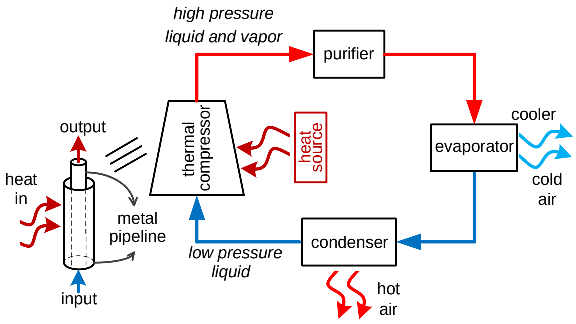



Fig. 4. Simplified cooling cycle of the absorption cooler.

The cooler needs a heat source to heat up low pressure volatile liquid. The heat source of the system can be a resistance heater, natural gas heater or renewable energy such as solar or geothermal heater. Generally resistance heaters are used for home type absorption coolers [22]. The heater part of the cooling loop is metal pipeline; therefore, structure of the absorption cooler inherently seems very suitable to be heated by induction heating.

## IV. ABSORPTION COOLER WITH INDUCTION HEATER

The self oscillated induction heater is implemented with 50 V dc voltage source and it has 60 turn induction coil, absorption cooler metal pipeline as heating load, IRFP250N power MOSFETS ($R_{dson} = 0.075\ \Omega$) [23] and 0.2 μF resonant capacitor as shown in Fig. 5. In the circuit, loaded induction coil parameters are defined as $R = 6\ \Omega$ and $L = 60$ μH. Maximum load current is calculated as 5.24 A by using (5).

This current also flows through the primary current of driving transformer. According to maximum load current, turn ratio of the current transformer must be selected not to exceed the zener diode power. BH curve of current transformers is not linear because of its non-ideal characteristic. Therefore turn ratio of current transformer must be selected sufficiently bigger than $L_{mcr}$ value to result appropriate magnetizing inductance.

Fig. 5. Self oscillated induction heater and absorption cooler.

Self oscillating driving circuit is designed with PHILIPS TN23/14/7-3F3 toroid core [24] and 12V/1.3W BZX85C12 zener diodes to limit $V_{gs}$ voltage. With the consideration of maximum load current and zener diode power, turn ratio of current transformer is chosen as 1:50:50 ($n_p$:$n_{s1}$:$n_{s2}$).

At resonant frequency, critical magnetizing inductance can be calculated as 1246 μH by using (12). Magnetizing inductance of designed driver circuit is calculated as 3125 μH and it is sufficiently bigger than the critical value. According to calculated results, designed driver circuit is suitable for resonant network at near resonant frequency. Soft switching coil ($L_{ss}$) is added to self oscillating driver circuit as 24 windings on TN23/14/7-4A1 core to keep the ZVS switching conditions.

Figure 6 shows simulation and experiment results of load current and driving voltage of self oscillating inverter. The switching frequency (47.17 kHz) is a bit bigger than the resonant frequency (45.94 kHz), and the load current is lagging from the driving voltage. So, soft switching is achieved. Calculated, simulated and measured results of load current and input power are given in Table I.

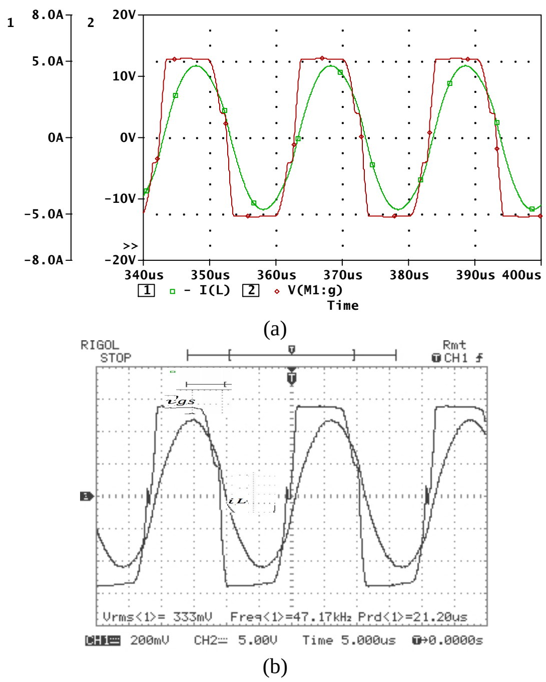
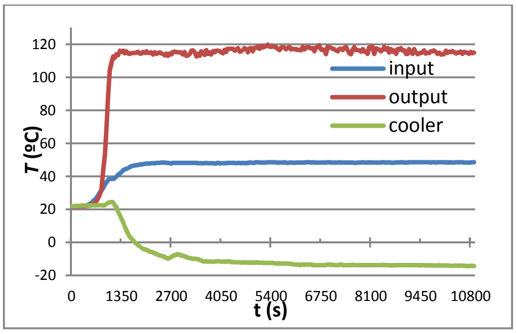



Fig. 6. Load current and driving voltage results: (a) simulation; (b) experiment (CH1: $i_L$ (100mV ≡ 1A), CH2: *V*gs)).

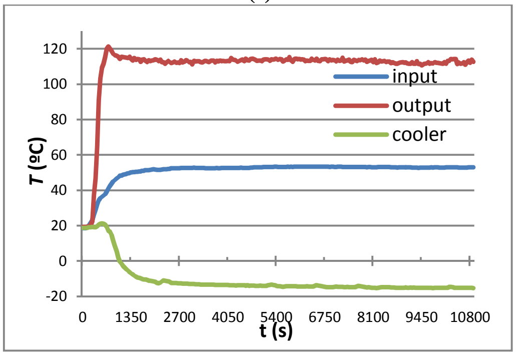
TABLE I. LOAD CURRENT AND INPUT POWER ($f_s$=47.17KHZ).

| | Calculated | Simulated | Measured |
|---|---|---|---|
| $I_m$ (A) | 5.11 | 4.69 | 4.72 |
| $I_{L,rms}$ (A) | 3.668 | 3.41 | 3.33 |
| $P_{in}$ (W) | 81.7 | 74 | 75 |

Heating and cooling temperature curves of both 75W resistance and induction heated absorption cooler are given in Figure 7. The induction heated absorption cooler has fast and stable heating/cooling response than the conventional system.




(a)




(b)

Fig. 7. Temperature curves of absorption cooler: (a) the resistance heated absorption cooler; (b) the induction heated absorption cooler.

## V. CONCLUSIONS

Self oscillated inverters are especially used in electronic ballasts circuits. In this study self oscillated series resonant half bridge inverter topology is implemented to a 75W induction heater used for home type absorption cooler. The induction heater is an efficient heat source for absorption cooler as contactless, continuous, uniform and regional heating can be achieved. The main advantages of the designed system are fast response, soft switching and resonant tracking with low cost and good heating/cooling performance. The self oscillated inverter maintains ZVS conditions for all the heating period without compromising the low cost and simplicity. The self oscillated induction heated absorption cooler can be appropriate solution for renewable energy based cooling systems.

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