# Systematic Approach to High Efficiency Resonant Converter used in Domestic Heating Application

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*Abstract:* The main objective of this project is to develop the analysis and design of a new ac–ac resonant converter applied to domestic induction heating. The proposed topology, based on the half-bridge series resonant inverter, uses only two diodes to rectify the mains voltage. The switch operates in soft commutation mode and serves as a high frequency generator. switch-off transitions. Moreover, this topology doubles the output voltage, and therefore, the current in the load is reduced for the same output power. As a consequence, the converter efficiency is significantly improved. A circuit model for AC to AC converted induction heating system is also proposed

*Index Terms:* Home appliances, induction heating, inverters, resonant power conversion.

## I. INTRODUCTION

**D**OMESTIC induction technology has become more popular in recent years due to features such as efficiency, safety, and accurate output power control, which outperform other traditional domestic heating technologies. The design of these appliances involves the research and development of efficient reliable cost-effective power electronics systems [1]. The main blocks of an induction cooking appliance are outlined in Fig. 1. The energy taken from the mains is filtered by an EMC filter, which prevents the device from inserting interferences, and it provides immunity to voltage transients. Afterward, the voltage is rectified and filtered, generating a dc bus. A low value of filter capacitor is chosen to get a high PF, and, as a consequence, a high-ripple dc bus is obtained. Then, the resonant inverter supplies variable-frequency current(20–100 kHz) to the induction coil. This current produces an alternating magnetic field, which causes eddy currents and magnetic hysteresis heating up the pan.
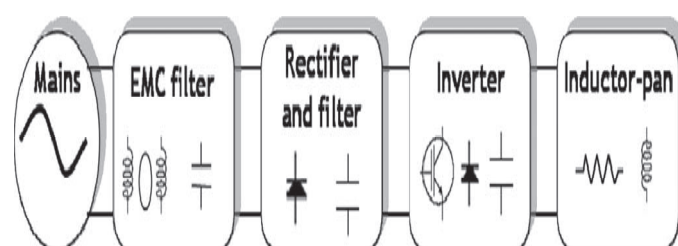


Figure. 1. Induction cooking appliance block diagram.

The half-bridge series resonant inverter (Fig. 2) is the most employed topology due to its simplicity, its cost-effectiveness, and the electrical requirements of its components [2]–[4]. The resonant tank consists of the pan, the induction coil, and the resonance capacitor . Induction-coil-and-pan coupling is modeled as a series connection of an inductor and a resistor, based on the analogy of a transformer, and it is defined by the values of Leq and Req [5]. These values change mainly with excitation frequency ω, pan material, temperature, and inductor–pan coupling. Designing an appliance that is able to heat different

materials with the same precision has been a challenging task since the beginning of technology development [6], [7]. In addition, cooking appliances require accurate power control over a wide range to fulfill the user requirements. This implies a wide operation range, where a ZVS condition must be fulfilled to ensure high efficiency [8], [9]. The principle of operation is based on the generation of a variable magnetic field by means of a planar inductor below a metallic vessel [1], [2]. The mains voltage is rectified and after that an inverter provides a medium-frequency current to feed the inductor.

The usual operating frequency is higher than 20 kHz to avoid the audible range and lower than 100 kHz to reduce switching losses. The most used device is the insulated gate bipolar transistor (IGBT) because of the operating frequency range and the output power range, up to 3 kW. Nowadays, most designs use the half-bridge series resonant topology because of its control simplicity and high efficiency [3]–[7].

In the past, several ac–ac topologies have been proposed to simplify the converter and improve the efficiency [8]–[10]. Considering the induction heating application, several resonant matrix converters featuring MOSFETs [11], [12], IGBTs [13], or RB-IGBTs [14], [15] have been proposed. However, the final efficiency and cost are compromised due to the use of a higher number of switching devices. Other approaches, commonly used in electronic ballasts, simplify the rectifier stage in order to improve the converter performance [16]–[21]. This topology, known as half-bridge boost rectifier, reduces the switch count while keeping the same performance as more complex solutions.

The aim of this paper is to propose a new topology to improve the efficiency while reducing the power device count for induction heating applications. The proposed topology is based on the series resonant half-bridge topology and requires only two rectifier diodes. The effective output voltage is doubled ,as in [22], [23], allowing a significant current reduction in the switching devices. Moreover, the proposed topology can operate with zero-voltage switching conditions during turn-on for both switching devices, and also during turn-off transitions for one of them. As a consequence, the efficiency is improved

while the device count is reduced. This paper is organized as follows. Section II describes the proposed topology. In Section III, a deeper analysis of the power converter is performed. Sections IV show the main simulation and experimental results, respectively. Finally, Section V draws the main conclusions of this paper.

## II.    PROPOSED POWER CONVERTER

The proposed topology (see Fig. 1) employs two bidirectional l switches SH and SL composed of a transistor TH or TL , typically an IGBT, and an antiparallel diode DH or DL , respectively.  The mains voltage vacis rectified by two diodes DrH   and  DrL, but only one of them is activated at the same time. This operation increases efficiency with regard to classical topologies based on  full-bridge diode rectifier plus a dc-link inverter. The proposed topology is a series–parallel resonant converter. The inductor–pot system is modeled as an equivalent series resistance Req and inductance Leq, as shown in Fig. 1 [24]. This topology implements resonant capacitors Cr and may use a bus capacitor Cb. Due to the symmetry between positive and negative mains voltage, both resonant capacitors have the same value. An input inductor Lsis used to reduce the harmonic content to fulfill the electromagnetic compatibility regulations.
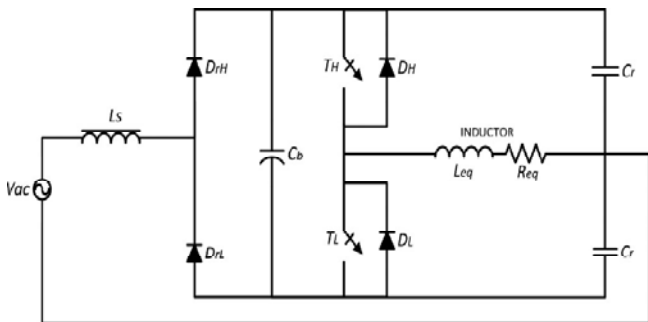


Figure 2 Proposed Converter

## III.     ANALYSIS

The topology presents symmetry between positive and negativeac voltage supply. Its symmetry simplifies analysis and makes possible to redraw the circuit.
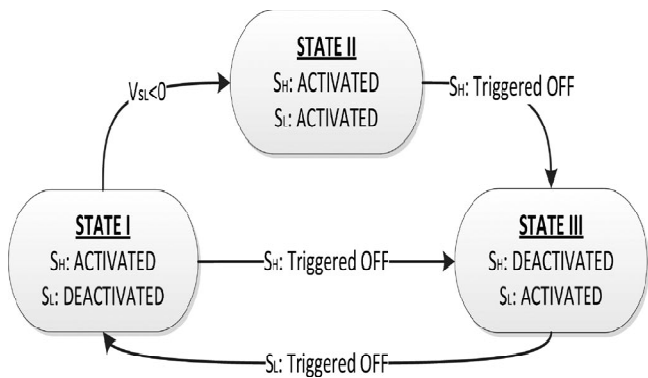


Figure. 3.1 States and transition conditions

Although this topology uses different resonant configurations, parallel and series, and different resonant tanks for each of them, it is possible to use a normalized nomenclature based on series resonance. Fig. 3 shows the simple  transition conditions for each state.

## STATE I:  $S_H$ Activated : $S_L$ Deactivated

State I operates with the high-side switching device SH triggered-on and activated and the low-side switching device (SL ) triggered-off. State I begins when SL is triggered OFF. In this moment, the antiparallel diode DH conducts and SH can be triggered ON ensuring ZVS switching-on conditions. Transitions from this state can lead either to state II or state III. If voltage across SL reaches zero and DL starts conducting, the transition condition to state II is fulfilled. On the other hand, if SH is switched OFF when TH conducts, the next state is state III.
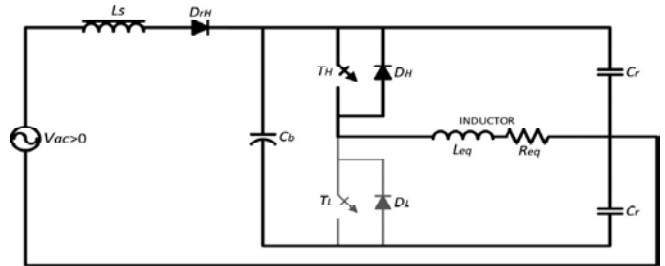


Figure 3.2  Equivalent circuit for STATE I.

## STATE II:  $S_H$ Activated: $S_L$ Activated

State II is characterized by the conduction of both switching devices, although only SH is triggered ON. That is, TH and DL conduct at the same time. Current through load is supplied by both devices (TH and DL ), and consequently, low conduction stress for the devices is achieved.
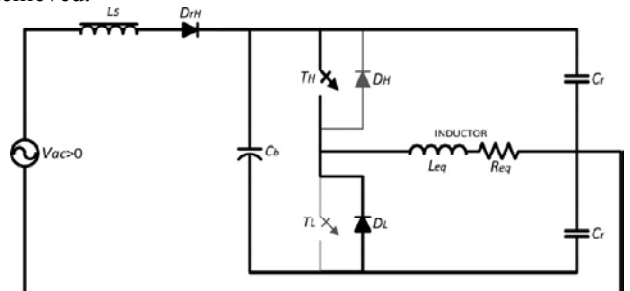


Figure 3.3  Equivalent circuit for STATE II.

The equivalent parallel resonant circuit is set by the inductor electrical parameters in parallel with both resonant capacitors. Cb is short-circuited by both switching devices. This state starts when the voltage across SL reaches zero. At this moment, DL starts conducting at the same time as TH is triggered ON.

This state finishes when SH is triggered OFF and the next state is state III. The main benefit results of the lower switch-off current achieved when SH is triggered OFF, due to the fact that the load current is supplied by both devices. In addition, SH achieves ZVS conditions during both switch-on and switch-off transitions, reducing consequently the switching losses.

## STATE III:  $S_H$ Deactivated: $S_L$ Activated

State III is defined by the conduction of SL while SH is deactivated. The equivalent resonant circuit is set by one resonant capacitor in parallel with the series connection of the Cb capacitor and the parallel connection of the inductor and the other one resonant capacitance. Note that when Cb is zero, the equivalent resonant circuit is a series RLC circuit composed of the inductor–pot system and one resonant capacitor. This state starts when SH is triggered OFF. At

this moment, DL starts conducting and SL can be triggered ON achieving ZVS switch-on conditions. This state finishes when SL is deactivated, and the next state is state I.
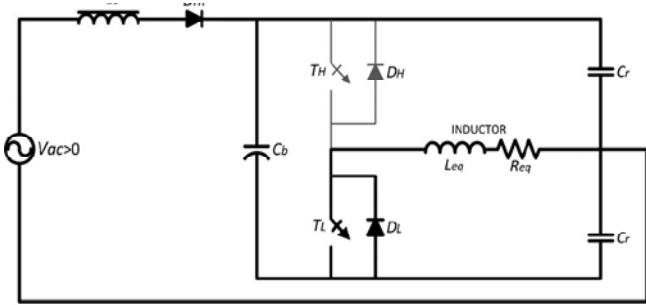


Figure 3.4 Equivalent circuit for STATE III.

By using the space-state analysis presented in Section III, two operating modes. Both of them achieve ZVS switch-on conditions; however, only the first operation mode can achieve the ZVS switch-off conditions for S.

The operating principles of the circuit are illustrated by Fig.3.1 Fig,3.2 Fig,3.3, and the theoretical waveforms are shown in Fig.3.4
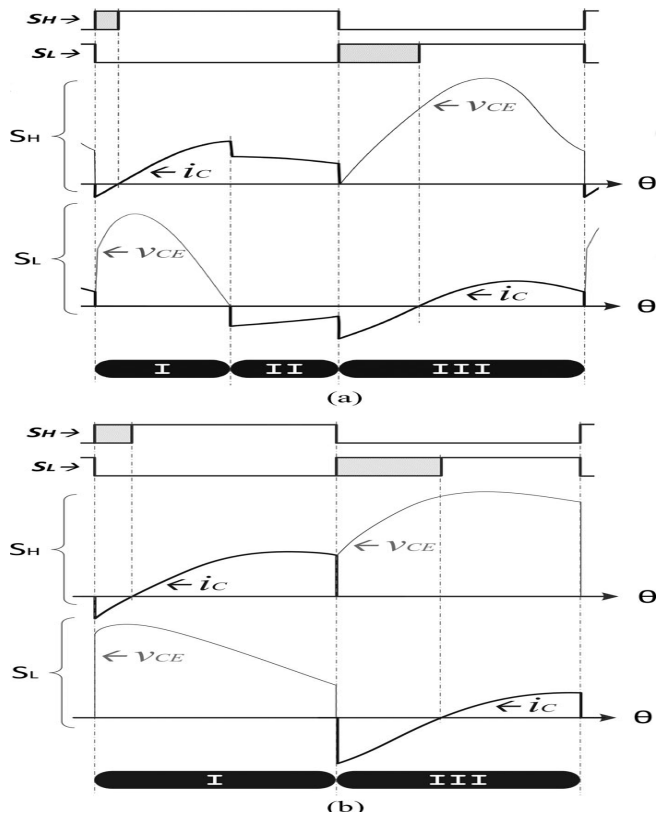


Figure 3.5 Theoretical Analysis Wave form

The first operation mode uses the three states described earlier: I, II, and III. It makes possible to achieve ZVS conditions for the high-side switch in state II.

## IV. SIMULATION RESULTS

The Resonant converter fed induction heater is simulated using Matlab simulink and their results are presented here. The circuit model of resonant converter is shown in Fig.4 Scopes are connected to measure output voltage, driving pulses and capacitor voltage.
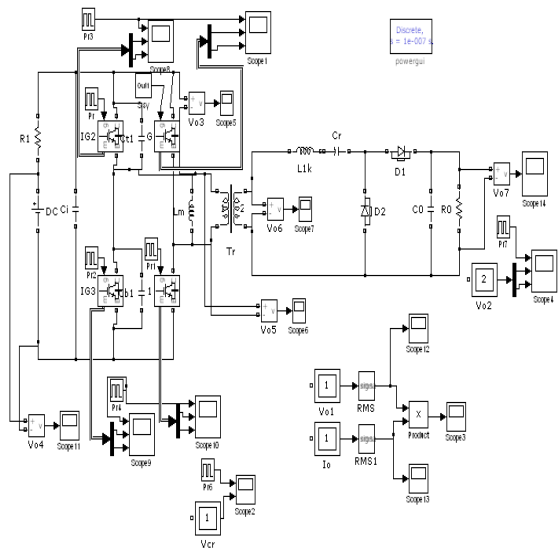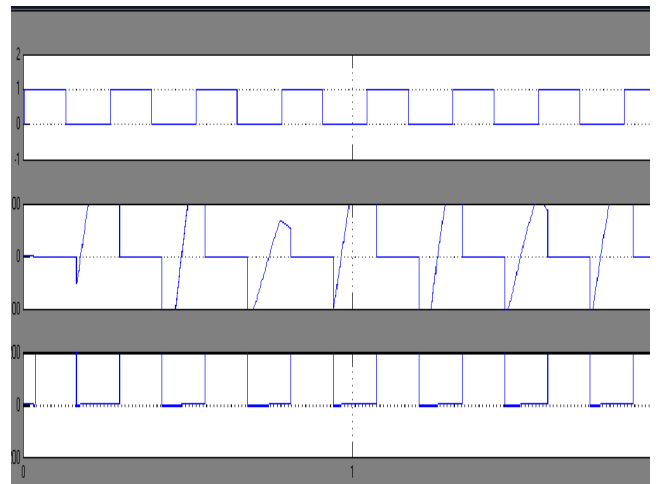


Figure.4.1. open loop Circuit



Figure 4.2 Main Control Signals And Waveforms.

By using the space-state analysis presented in Section III, two operating modes can be described. Both of them achieve ZVS switch-on conditions; however, only the first operation mode can achieve the ZVS switch-off conditions for SH . The first operation mode uses the three states described earlier: I, II, and III. It makes possible to achieve ZVS conditions for the high-side switch in state II.
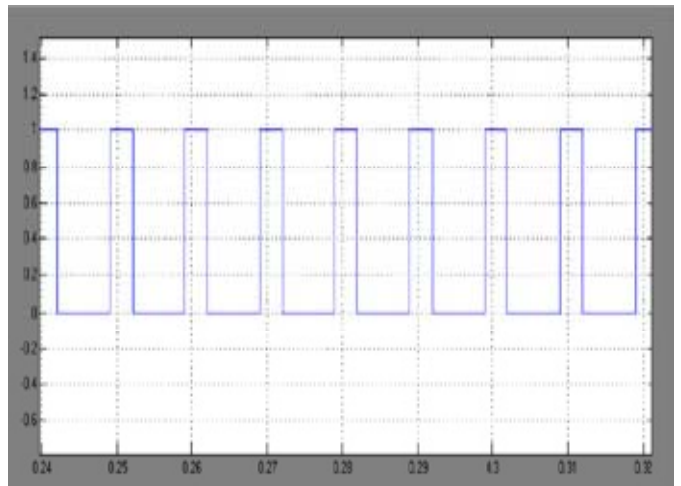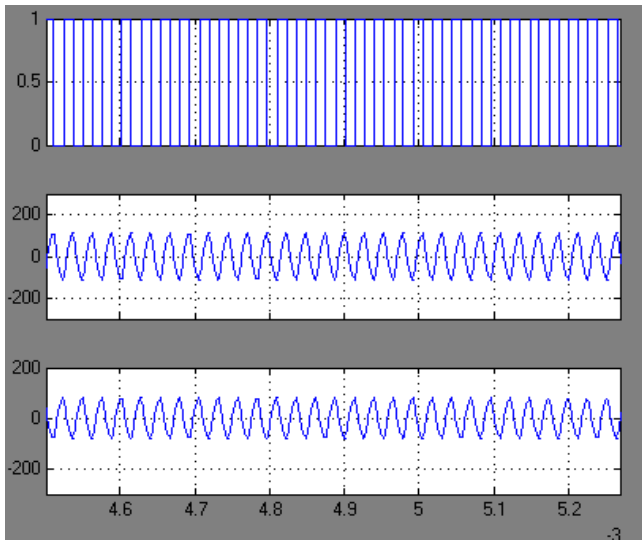


Figure 4.3 Driving pulse

Figure 4.4 Output voltage waveform of open loop system

The output of PI controller controls the dependent source. Response of open loop system is shown in fig 4.4.

The closed loop circuit model of resonant converter is shown in Fig.4.5. Scopes and displays are connected to measure the output voltage.
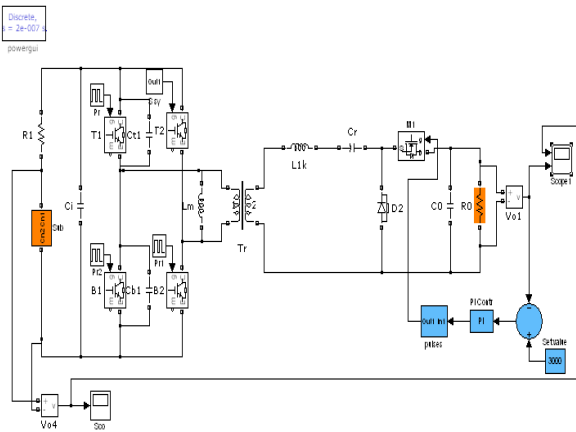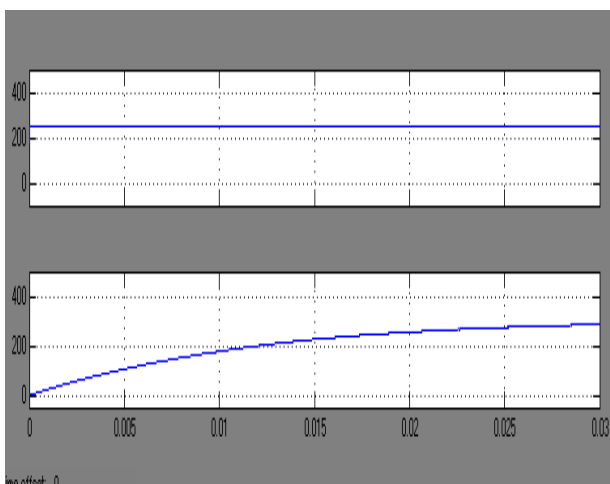


Figure.4.5.Closed loop Circuit



Figure 4.6 Output voltage waveform of closed loop system

## V.    CONCLUSION

This paper presents a new ac–ac converter applied to domestic induction heating. An analytical analysis has been performed in order to obtain the operation modes that describe the proposed converter. The converter can operate with zero-voltage switching during both turn-on and turn-off commutations. Besides, the output voltage is doubled compared to the classical half-bridge, reducing the current through the switching devices. As a consequence, the power converter efficiency is improved in the whole operating range.

## VI.    ACKNOWLEDGEMENT

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