New Optimised IGBTs for Induction Cooking

The uniqueness of induction cooking lies in heating the pot or the pan electromagnetically and not thermally. When a pot or a pan is placed in the path of a varying magnetic field, eddy current is induced in it. The eddy current losses, thus produced, generate heat, which raises the temperature of the pot or the pan and as a result food, contained therein, is cooked. A new fast IGBT with an anti-parallel FRED is best suited for these high-frequency switching applications. **Abhijit D. Pathak, IXYS Corp., Santa Clara, USA, and Kyoung-Wook Seok, IXYS Korea Ltd**

Induction Cooking has several benefits and unique features. As soon as the induction cooker is turned on, heat is generated within one second inside the pot or the pan. This allows very quick start-up of cooking. Heating process times can be reduced thus, allowing higher output in shorter times. Induction cookers are up to 90% efficient in converting electrical energy into heat. Gas cooking is only 35% efficient. Electrical cooking ranges and ovens also have poor efficiency and are slow as well.

Unlike gas or electrical heaters, induction cookers produce much less waste heat and hence, there are no adverse effects on air conditioning. This results in net energy savings. Induction cookers have pin point accuracy. That means, a precise amount of heat is produced quickly and can also be controlled instantly within the cooking pot. Additionally, induction cookers offer the facility to produce the exact amount of heat every time and the entire heating/cooking cycle can be repeated precisely.

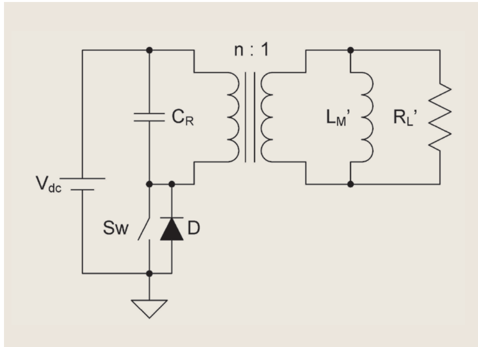

Figure 1: Single switch induction heating circuit

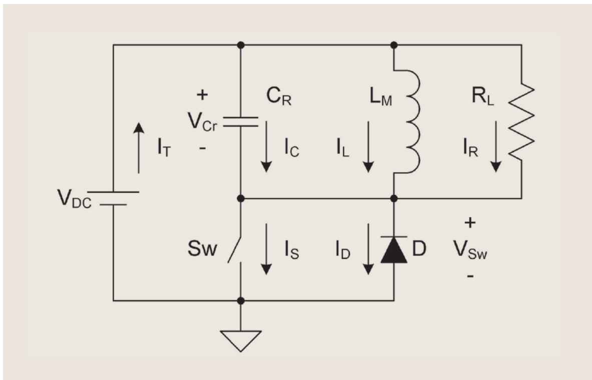

Figure 2: Currents and voltages in the simplified induction heating circuit

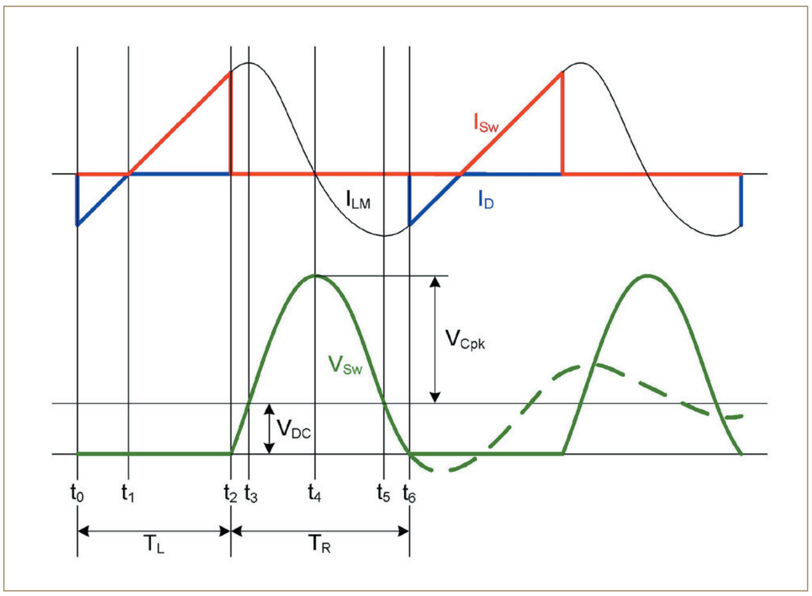

Figure 3: Operating modes of the induction heating circuit

Theory of induction cooking

When an alternating current is flowing through a coil, its magnetic field induces voltage in conductive objects in proximity, which is proportional to the rate of change of flux linkages. For the induction cooker, the coil is wound on a plastic former, which has about six segments of ferrite rectangular bars, which enhance and bend the flux lines towards the pot or the pan. In effect it is not purely an air core; it will have permeability higher than an air core.

It is also interesting to note that, depending on the geometry of the pot or the pan, its placement on the cooker and the food being cooked, inductance will vary slightly. One can think of the pot or the pan as being one turn secondary of a transformer, whose primary is the coil. The pot or pan consists of dual layers. Inside is Teflon coated aluminum and outside is iron.

Because the switching frequency is at or near 30kHz, litz coil (in which many strands of thinner gauge super enameled polyester insulated copper winding wire are used in parallel) is employed to wind the coil to circumvent losses due to skin effect in the copper wire. To optimise its inductance, its thickness is kept at minimum and ferrite rectangular bars are inserted from inner diameter to the outer diameter uniformly at six locations radially, so as to enhance and direct flux linkages to the pot or the pan.

The coil and pot forms a transformer whose turns ratio is (n: 1). According to Figure 1, the cooking pot/pan forms the secondary. Because the peak voltage applied to the switch is about 1000V and switching frequencies range between 20 and 35kHz and peak currents go up to 30A, the preferred switching device is an IGBT. Figure 2 shows currents and voltages in a simplified induction heating circuit.

According to the current polarity and the switch status, operation modes of the circuit are shown in Figure 3:

t_0: The voltage V_{Sw} becomes zero. The diode D starts conducting inductor current.

$t_0 \sim t_1$: I_{Lm} linearly increases with the slope of V_{DC}/L_M. Switch is gated-on in this period.

t_1: As inductor current I_{Lm} becomes zero, the diode stops conducting.

$t_1 \sim t_2$: I_{Lm} linearly increases through the switch with the slope of V_{DC}/L_M.

t_2: Switch Sw is turned off.

$t_2 \sim t_3$: I_{Lm} increases. V_{Sw} increases.

t_3: I_{Lm} is at maximum. V_{Cr} is zero.

$t_3 \sim t_4$: I_{Lm} decreases.

t_4: I_{Lm} is zero

$t_4 \sim t_5$: I_{Lm} goes to negative.

t_5: I_{Lm} is at negative maximum. V_{Cr} is zero.

$t_5 \sim t_6$ I_{Lm} increases.

t_6: It is the same as t_0.

In absence of diode, after t_6, V_{Cr} will continue oscillating with decay as the dashed curve. The dashed line settles to V_{DC}.

At hard switching, the switch is turned on at a finite V_{SW} (non-zero). In a very short time, the switch charges up the capacitor. The switch current is very large and is not comparable to the currents through the inductor and load resistor. High EMI will result due to hard switching and, high capacitor discharging current may induce IGBT failure.

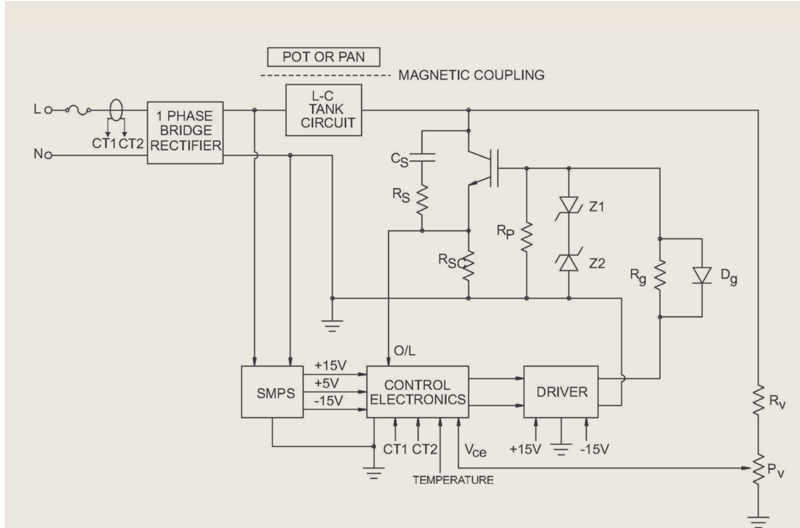

Figure 4: Block diagram of induction cooker

Circuit operation

Keeping simplicity and economy in mind, a schematic is suggested using the ZVZCS resonant mode switching of an IGBT, for varying the current in the coil 'L2', which resonates with the capacitor 'C2' at the switching frequency (Figures 4 and 5). The switching frequency and the pulse width (duty cycle) determine the amount of current flowing in the coil, whose secondary is the cooking pot or pan in which the eddy current is induced, thus controlling the output power.

A closed loop control of temperature can be realised using a temperature sensor, with additional inputs of mains and load currents, to provide a stable and adaptive control resulting in predictable performance. However, more often than not, an open loop system is used with high temperature cut-off being used for safety. The open loop system is less expensive and more reliable. A low value filter inductor (L1) and filter capacitor (C1), placed just after the bridge rectifier, prevents noise from entering the circuit and circuit noise from travelling back into the mains. By keeping C1 value very low, a high input power factor is maintained. Even though the resultant waveform is full wave rectified output, it is of little consequence, as the ultimate purpose of heating and cooking the food is still accomplished with all objectives intact. The only detrimental

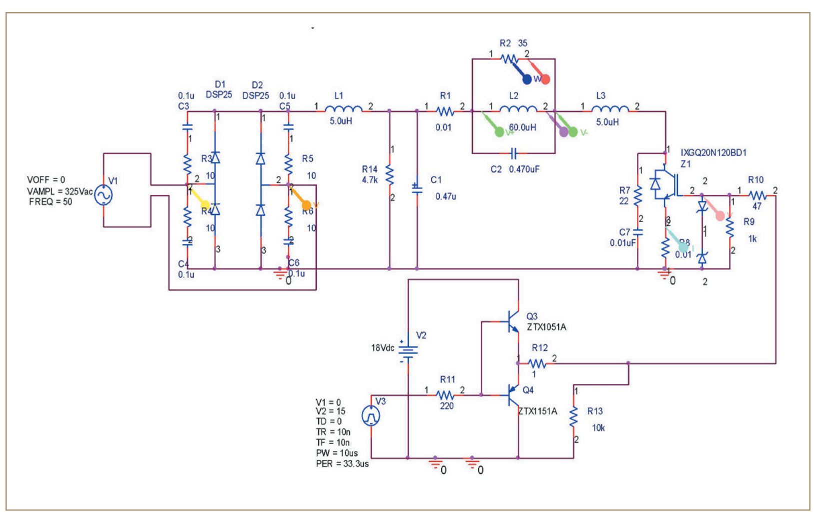

Figure 5: OrCAD schematic of the induction cookert

effect of the circuit is the high impressed voltage across the IGBT's collector and emitter. As the switching frequency chosen is 30kHz, it generates no audible noise, but still allows a small coil size to handle up to 1.8kW. Output power levels from 1 to 3kW are possible with some design modifications and choice of appropriately rated IGBTs.

The mains supply voltage is full wave rectified and lightly filtered by L1 and C1, so as to inexpensively maintain near unity power factor. The output from this is fed to the tank circuit consisting of L2 and C2, which is tuned around 30kHz. L2 actually represents primary winding of a transformer, whose secondary is the pot or the pan that is placed above it. Here 35Ω represents reflected equivalent resistance of the pot or the pan's conductive surface, in which eddy current flows for 1.8kW maximum power output. Q1 is the IXGQ20N120BD1, IGBT with an anti-parallel FRED. R7 and C7 across the IGBT form a snubber (not required for a perfectly tuned circuit) to reduce switching losses in the IGBT, while R9 enhances dV/dt immunity. R10 determines the rise time and a Schottky rectifier D17 (not shown in Figure 5), connected in anti-parallel across it, reduces fall time and tail current. The IXGQ28N120BD1 and IXGH30N120IH have also been experimentally tested in 1.8 to 2.5kW cookers with excellent results.

In the block diagram (Figure 4) of the cooker, SMPS converts full wave rectified power into the regulated DC 15VDC, -15VDC and 5 VDC voltages needed to operate the control electronics and the IGBT driver. A pair of fast NPN/PNP transistors, configured in totem pole, can be used to drive the IGBT. It is prudent to choose high enough h_{fe} for the transistors to ensure saturated switching of the IGBT. Alternatively, a driver IC such as the IXDN409 could also be used for simplicity. Also, the gate drive circuitry should be designed to realise the required rise and fall times, and should enhance faster turn-off to keep switching losses at minimum level.

By measuring current drawn from the mains and the temperature of the pot or the pan, the control circuit can adjust the power being delivered to the pot or the pan by ZVZCS resonant control of IGBT. In Figure 4, the voltage drop across an R_{SC} provides a means to implement overload protection for the IGBT. Z1 and Z2 are 18V, 400mW Zener diodes to protect the gate of the IGBT. One has to ensure close magnetic coupling for optimum power transfer to the pot or the pan. A potentiometer divider consisting of R_V and P_V provides feedback of instantaneous collector voltage to the control circuit.

The entire circuit works as a closed loop, controlling the preset temperature for different types and quantity of foods contained in the pot or the pan. In Figure 5, a set of L2 and C2 (L2 = 60μH, C2 = 0.47μF), which also resonate at 30kHz, are used. Also, inductor L3 reduces dissipation in the IGBT by decreasing current spikes at turn-on and turn-off. In most designs, however, an open loop control is used. The temperature (power level) allows decreasing the switching frequency and increasing PWM duty cycle in such a way as to increase transfer of electromagnetic energy to the cooking pot or pan for cooking food faster. An operation cycle below 20% is not recommended. Also, the high temperature cut-off limit for IGBT case temperature should not be set too low, otherwise nuisance tripping will result. This is a common cause of false alarm.

Conclusion

Both PSpice simulation and experimental investigation have given very encouraging results, while using IGBTs: IXGH20N120BD1, IXGQ20N120BD1, IXGH28N120BD1, IXGQ28N120BD1 and IXGH30N120IH. IXGH28N140IH was successfully used in cases where mains voltage could range to higher values. These IGBTs, designed for induction heating applications, also survived avalanche tests, which give idea about their ruggedness. Induction cookers do experience unexpected power failures, which produce large voltage spikes across IGBT collector and emitter.

The PSpice simulations have given insight into the resonant mode ZVZCS circuits; this was followed by experiments, and the waveforms so observed tallied with the PSpice simulation, thus proving the theory and designs. For building higher capacity induction cookers, higher power IGBTs such as IXGH35N120BD1 can be used, or IGBTs can be used in parallel with some current sharing techniques. This is an excerpt of a paper first presented at the Prism Business Media 2006 PowerSystems World Conference, Long Beach, California, containing much more theory on induction cookers.