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Maximize The Efficiency Of Induction Heating By Minimizing IGBT Losses

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In recent years, an increase in the number of electrical appliances in use has led to a steady rise in the total energy consumption within the average home. This trend is occurring in the majority of western countries and in emerging nations too. The costs associated with this energy usage have also increased as fuel resources have become scarcer and utility companies have raised their prices as a result. In order to maximize the amount of power obtained from the electrical grid, so that utility bills are kept in check and carbon emissions are also lowered, it is vital that greater effort be put into developing more energy efficient appliances for the home.

Induction cookers, which use electro-magnetically generated heat energy for cooking, are considerably more energy efficient than the standard household electric cookers that we are familiar with. Furthermore, as the heat is generated by induction, rather than through conduction, induction cooking proves much safer. With induction stoves, any human body parts placed on the cooking surface will not get burnt.

Within the typical induction cooker, a switched-mode power converter employing an IGBT power switch produces a magnetic field, which is then converted to heat by the cooking vessel. Through proper selection and use of the IGBT, designers can minimize its losses in the induction cooker and thereby maximize the overall efficiency of the application.

This article explains the principles of operation behind induction cooking and gives an overview of the various sources of loss in the application including those of the IGBT for the case where soft switching is employed. The two dominant losses in the IGBT—conduction and turn-off losses—are discussed in detail, providing designers with tips on how to accurately measure these losses so that IGBT performance in the application can be properly assessed and optimized.

Principles Of Induction Heating

A typical quasi-resonant flyback topology used for induction heating applications is depicted in Fig. 1. Electromagnetic energy is generated and transferred to the cooking vessel using induction. There it is then transformed into thermal energy, thereby heating the vessel.

The induction that triggers the heating process involves rectifying a relatively low-frequency ac line input voltage using an uncontrolled switching device such as a diode. Switching the rectified voltage at a frequency between 20 kHz and 35 kHz produces a high-frequency magnetic flux. The cooking vessel acts as a lossy magnetic core which converts the magnetic field into heat energy. The main components used to generate and transfer this heat energy are the cooking vessel, an inductor, a resonant capacitor and an insulated gate bipolar transistor (IGBT.)

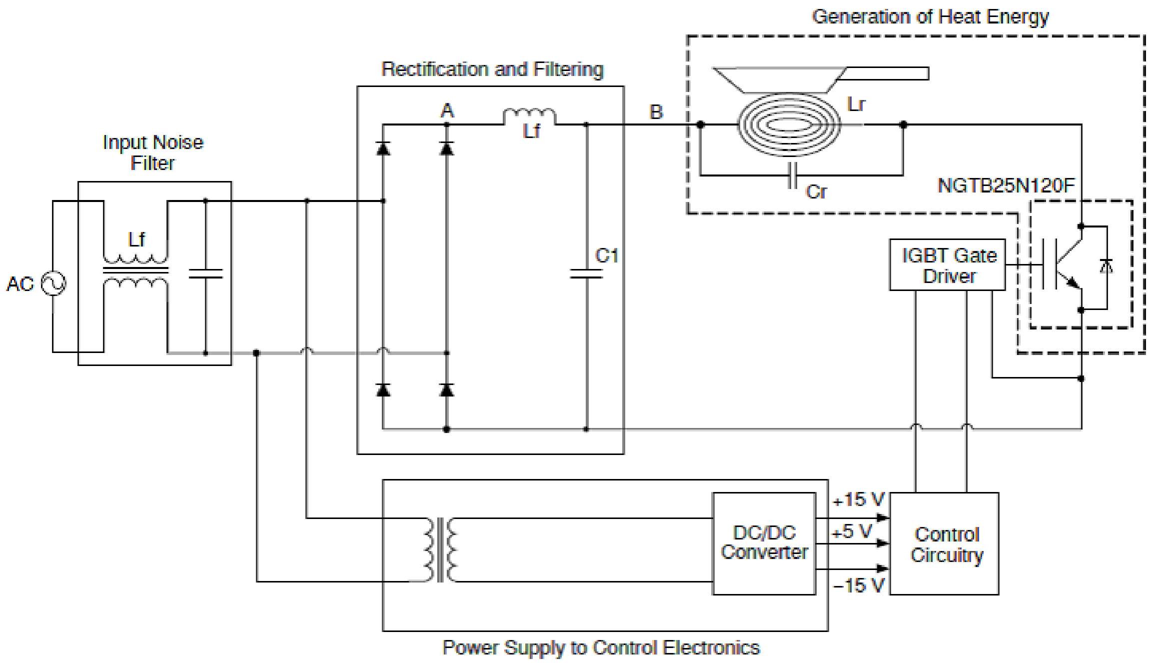

Fig. 1. Block diagram of single-ended topology of induction cooker.

The geometry of the inductor winding is very important when it comes to generating the magnetic field required to transfer heat energy to the cooking vessel. The inductor windings are spiral in shape and are wound around each other in a horizontal plane. This arrangement increases the surface area of the magnetic flux and makes the heating process more efficient. The concentration of these magnetic flux lines around the cooking vessel is further enhanced by using rectangular-shaped ferrite magnet bars, placed at equal intervals around the inductor windings. The use of multiple small conductors minimizes skin effect and reduces the inductive reactance (IR) losses in the coil. LR, shown in Fig. 1, is an air core inductor, which does not have the same sort of losses as conventional ferromagnetic core inductors.

The cooking vessel must be made of a magnetic material so that it can act as a core. At the switching frequency of the induction cooker, the thickness of the vessel is much too great for an efficient core and the eddy current losses are substantial. These losses convert the magnetic field into thermal energy, generating a great amount of heat in the vessel and cooking the food therein.

IGBTs with blocking voltages of about 1200 V are widely used in single-ended induction heating applications. During turn-off, the high voltage placed across the IGBT, together with its residual current, cause considerable turn-off losses. During the on-state of the IGBT, the power lost due to its saturation voltage with load current and junction temperature (T_J) adds to the total loss in power. These losses reduce the overall efficiency of these applications. Understanding the cause of these losses and developing a reliable and relatively fast method to measure them is important, especially when looking into IGBT design optimization for induction cooker designs.

The total power lost in the IGBT in this application consists of turn-on, conduction, turn-off and diode losses. The contribution of the diode losses to the total power loss is negligible and the turn-on losses can be significantly minimized, if zero voltage switching (ZVS) techniques are employed. However, ZVS is not achieved at all operating power levels of the induction cooker. Since one end of the tank circuit is connected to the rectified input voltage, zero-state switching only occurs at power levels that resonate the tank circuit such that it reaches 0 V. Under some light-load conditions, the tank circuit voltage will not reach 0 V on the collector of the IGBT and therefore switching at a zero state is not achieved and the turn-on power losses will increase.

Conduction Losses

As the most dominant contributors to the total power loss are normally conduction and turn-off losses, let's look at each of these in more detail. The average power dissipated by the IGBT is expressed mathematically in the following equation:

$$P_{Ave} = \frac{1}{T_S} \int_0^{T_S} \left[V_{CE}(t) \times I_{CE}(t) \right] dt$$ (Equation 1)

For conduction losses, this equation can be re-written as:

$$P_{Ave} = V_{CE(sat)}(t, I_{CE}, T_J) \times I_{CE} \times D$$ (Equation 2)

From this it can be seen that conduction losses are dependent on the load current, $V_{CE(sat)}$, and the duty cycle. The value of $V_{CE(sat)}$ is not constant but varies over time. It is also dependent on the load current and the IGBT's T_J value. In induction cooker applications, the control circuitry varies the duty cycle in direct proportion to demand for cooking power. Consequently, conduction losses will be at their greatest at the highest cooking power level because all the parameters in equation 2 will have their maximum values at that level.

Fig. 2 shows the variation of $V_{CE(sat)}$ with I_{CE} at T_J = 67°C for a selected switching cycle. The data in Fig. 2 was obtained from a commercially available induction cooker with a clamped circuit being used to measure $V_{CE(sat)}$. This circuit clamps V_{CE} at 10 V when the IGBT is switched off, which allows the oscilloscope to use a low volt/div setting so that V_{CE} can be accurately measured.

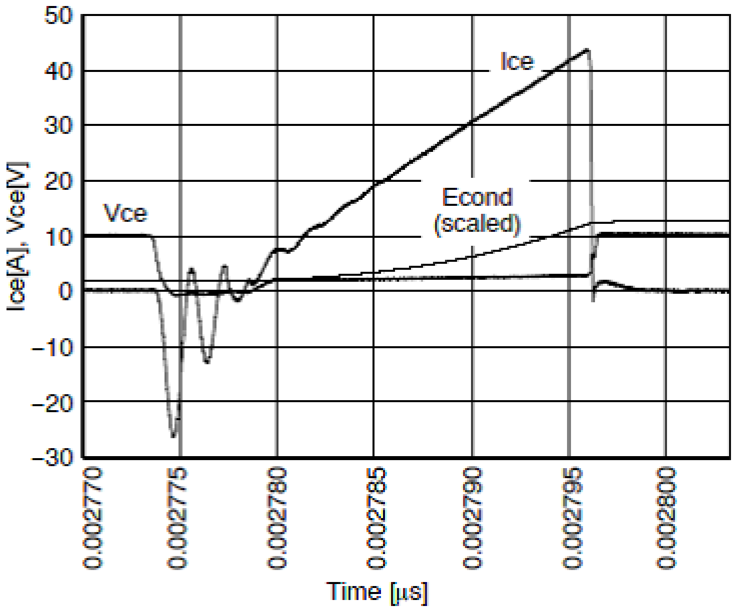

Fig. 2. Variation of $V_{CE(sat)}$ with I_{CE}.

Turn-Off Losses

The turn-off element of the induction cooker waveforms can be seen clearly in Fig. 3. These losses are influenced by the IGBT's residual current, the slew rate of V_{CE} and the switching frequency. The residual current results from minority carriers trapped in the drift region after the IGBT is switched-off. Factors that influence the rate of combination of these minority charge carriers include the doping concentration, the buffer layer thickness and the doping technology used.

The switching frequency is determined by the desired cooking power level and the switching control algorithm of the application. It is important to verify IGBT performance in the target application during each stage of the design and development process. This performance verification can be done by measuring the IGBT's losses in the application.

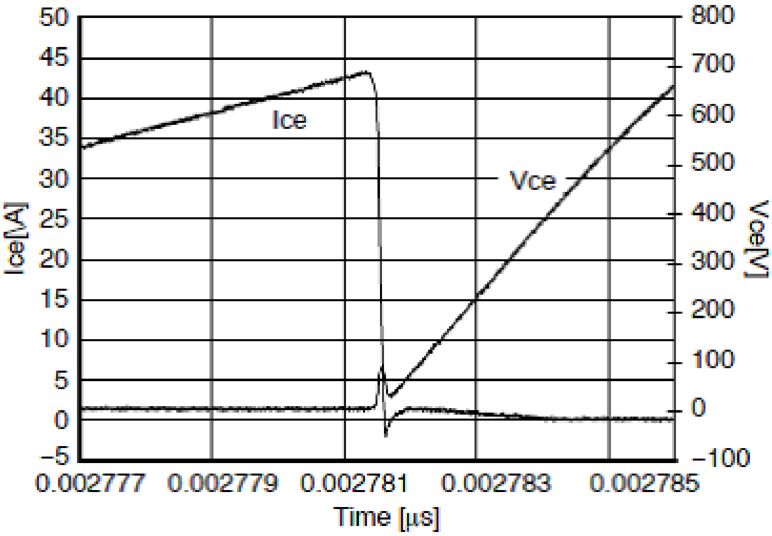

Fig. 3. Measurement of turn-off losses.

Induction cookers have proved to be around 25% more efficient than conventional electric cookers. In soft-switching induction cooking applications, conduction losses and turn-off losses are the most important losses to be considered when looking to specify an IGBT for inclusion in the system, contributing comparable amounts. Accurate measurement of these losses helps to provide the necessary data to evaluate IGBT performance during the system development process and thereby ensure that efficiency levels are maximized.

About The Author

Alan Ball has 35 years experience in switching power supply design and analysis. His career has encompassed both military and commercial power supply design. For the past fifteen years, Alan has been involved with applications support for semiconductor products, working for ON Semiconductor where he has held various application engineering positions. Alan is currently the technical director of engineering for the Digital Consumers Group at ON Semiconductor.

Previously, Alan worked for Power Paragon as an engineering manager and general manager of the Airborne Power division. He holds a BSEE from Arizona State University, and an MBA from Keller Graduate School of Management. Alan holds approximately 25 patents.

For further reading on power management in induction heating applications, see the How2Power Design Guide, select the Advanced Search option, go to Search by Design Guide Category, and select "Appliances and White Goods" in the Application category.