**IGBT Definition for Single Ended Induction Heating Cookers**

**Cooking with Induction Heating Technology**

Induction heating is a well-known technology and very commonly used for cooking appliances because of its high energy efficiency. The single ended parallel resonant converter, despite its limitations, is now a well-used topology due to its lower system cost compared with other resonant topologies. The proper selection of the IGBT device’s key parameters results in a very efficient and reliable system.

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Induction heating (IH) is a well-known technology and very commonly used for cooking appliances. All IH cooking appliances operate using the electromagnetic induction phenomenon: an AC current flowing through a circuit (i.e. the heating coil) generates a variable magnetic flux, thus causing eddy currents to occur in a secondary circuit (i.e. the load to be heated). Due to the Joule effect, the electric energy caused by the induced current is converted to heat.[1]

Despite their higher initial cost compared to gas or electric cooking appliances and the need for special pans made of ferromagnetic materials, IH cooking appliances present benefits such as high energy efficiency, fast and safe cooking, and easy to clean cooktops that have made them popular around the world.

Since energy efficiency is one of the main objectives of IH cooking appliances, resonant converter topologies are mostly used due to soft switching operation (zero-current switching ZCS or zero-voltage switching ZVS) considerably reducing the converter switching losses and EMI generation.

In high-end IH cooking appliances; with power levels on each hob ranging from 1.2kW to ~3.0kW, the half-bridge and full-bridge series resonant converters (figure 2) are the most common topologies used. Yet, their large component count, heat sink size, and complex control schemes increase the cooker cost limiting their possibility to reach the low-end markets. As a result, and despite its limited power level and other potential drawbacks, the single ended parallel resonant converter has become an important alternative to the series resonant topologies and it is already largely used on IH single hob cooktops and rice cookers.

![Figure 1: Electromagnetic induction phenomenon in IH cooking appliances](image)

![Figure 2: Typical converters used in high-end IH cooking appliances](image)

**The Single Ended Parallel Resonant Converter**

The single ended parallel resonant (SEPR) converter (basic schematic and operating waveforms are shown in figure 3), consists primarily of a parallel inductor and capacitor resonant tank network, formed by Lr and Cr in the schematic; typically a single IGBT/Diode Copak device, and a small capacitor, shown as Cf, placed to help as an EMI filter and to provide a path, together with the Diode for the inductor’s resonant current flow. The main power source of this converter is the rectified, but not filtered, line voltage to achieve near unity power factor at the mains voltage.
For power levels close to 2.0kW, and for a reasonable IH cooker design, voltages up to or above 1200V and currents close to 60Apk must easily be supported by the converter as shown in the operating waveforms’ figure. A switching frequency control scheme is typically used, operating from ~20kHz to 60kHz switching frequencies in order to avoid acoustic noise; starting at the higher frequency for soft start operation and reaching the maximum power at the lower frequency.

**Operation of the SEPR Converter**

The typical waveforms of the IGBT’s Gate and Collector voltages, VGE and VCE; Collector current IC, and resonant inductor current IL are shown in figure 4. In addition, figure 4 shows IL's flow during a full converter's operation cycle to help the operation's explanation.

Mode 1 (t0-t1). At first, the IGBT Q1 is turned-on at ZVS condition and current flows through the resonant Inductor Lr from the rectified line voltage.

Mode 2 (t1-t2). The IGBT is turned-off at the desired peak current, then the resonant Inductor’s current starts to flow through the resonant Capacitor Cr, concluding when total inductor energy is transferred. At this point, the maximum resonant voltage is present in the resonant Capacitor Cr, and, therefore, the IGBT is blocking the maximum VCE voltage. If this is not considered during converter design, VCE voltage can be large enough to damage the IGBT.

Mode 3 (t2-t3). The Capacitor Cr resonates and the current flows through the resonant Inductor Lr in opposite direction, even after total Capacitor energy is transferred. The Capacitor Cr current stop when its voltage is equal to the supplied voltage.

Mode 4 (t3-t4). The Inductor’s resonant current flows through Capacitor Cf and Diode D1. It is during this time when the IGBT’s VGE voltage is applied. When total inductor energy is stored again on capacitor Cf, the IGBT starts conduction turning-on at ZVS condition and the process is repeated.

**Key Parameters of IGBT and Diode for SEPR Converter**

The majority of IGBT manufacturers have released 1200V IGBTs specific to IH applications and soft switching applications, mainly in Trench technology including reverse conducting IGBTs with monolithic body diode. The released IGBT’s nominal currents and packages are mostly targeting the induction cooking appliances market requirements (see table 1).

<table>
<thead>
<tr>
<th>Typical SEPR IH Cooker Requirements</th>
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<tbody>
<tr>
<td><strong>Output Power</strong></td>
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<tr>
<td><strong>Input Voltage</strong></td>
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<tr>
<td><strong>Switching Frequency</strong></td>
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**IGBT Device Requirements**

<table>
<thead>
<tr>
<th>Power Device</th>
<th>Copak IGBT + Diode</th>
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<tbody>
<tr>
<td>VCE Range</td>
<td>≥ 1200V</td>
</tr>
<tr>
<td>IC @ 100C Range</td>
<td>15A - 30A</td>
</tr>
<tr>
<td>Package</td>
<td>TO-247</td>
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Table 1 Typical SEPR IH Cooker and IGBT device requirements

For the proper IGBT selection on SEPR converter consider the following facts: in this converter the power losses are due to the IGBT’s VCE(ON) and soft turn-off energy (EOFF) losses. The IGBT operates at soft switching conditions as shown in figure 5; the turn-off switching losses are due mainly to the typical IGBT’s “tail” current because of the low dv/dt produced by the resonant capacitor, reducing the losses significantly. At turn-on, there are no losses due to the zero voltage switching condition generated by the previous conduction of the Diode. Therefore, both the VCE(ON) and “tail” current performance are the significant parameters for the IGBT; the right balance of these parameters is important to reduce power losses for this converter.
It is important to note that soft turn off energy is not related to the EOFF during hard switching included in most IGBT datasheets. This makes device comparison more difficult because a major contributor to losses in this application is not specified in datasheets. Figure 6 shows the disparity between soft switching losses as measured and hard switching losses specified in a datasheet.

For correct Diode selection on SEPR converter, the following facts should be considered: the Diode’s losses are due mainly to the forward voltage drop $V_F$, and the forward recovery voltage $V_{FR}$. The Diode has no Reverse Recovery Losses on this converter because it turns-off at ZVS condition, and this is because the IGBT is already ON during this stage, as shown in figure 7. Also, the Diode commuted OFF at low $di/dt$, typically lower than 10A/µs; this helps to have a smaller reverse recovery current. This means that during a short period of time, Inductor current is shared by the IGBT and Diode’s reverse recovery current. Attention needs to be taken with the Diode’s forward recovery voltage $V_{FR}$, because it could be a significant parameter if it is not optimized for this application. The Diode’s losses are significantly smaller compared to IGBT’s losses if it is adequately selected and optimized for this application.

The importance of the key parameters mentioned is exemplified in the chart on figure 8. This chart shows the IGBT Copack devices’ power losses performance on an IH cooker using SEPR converter. These devices have been released specifically for this application, however, the poor performance of the key parameters discussed have a significant impact on the final results. In this case, two competitor devices with higher nominal current, 25A and lower $V_{CEON}$ than IR’s 20A IRG7PH35UD1 device, show significant higher power losses in the IH cooker application. The performance of competitor
device “A” is an example of the importance of optimizing the diode for this application; it shows significant larger power losses, around 15W higher than IR’s device and this is due to its poor Diode’s forward recovery voltage performance. Competitor device “B”, with large turn-off “tail” current performance, shows around 5W higher power losses than IR device. These are two examples of poor application performance due to improper device key parameter’s definition.

SEPR IH Cooker’s Improved Reliability with Robust IGBT

In SEPR converter there is a direct inter-dependence between maximum achievable output power level and peak collector voltage VCEpk. Any increase in the input voltage will increase the output power and hence the VCEpk. Therefore, the IGBT device should be defined based on maximum stress levels, which occur at the peak of the rectified 50 or 60Hz line voltage as shown in the figure 9.

The typical IH cooker’s power level on the market is around 2kW maximum using 1200V VCE rating IGBTs. As mentioned, for power levels close to 2kW, VCEpk voltages up or above 1200V have easily to be supported by the IGBT, because making use of higher voltage IGBT increases significantly the cost and power losses in the system, due to the typical higher VCEON parameter per same die size area as a function of IGBT’s voltage increase.

At present, a big issue for SEPR IH Cookers is the large field failure rate due to the mains voltage transients. In countries like China or India for example, where these IH cookers are very popular, the mains voltage transients can reach up to 20% from nominal value, generating easily IGBT’s VCEpk voltages higher than nominal 1200V and hence, damaging the IGBT. For this reason, and for specific 1200V rated IGBT, IH cooker’s manufacturers prefer higher voltage capacity than nominal 1200V VCE to be safe during the mains voltage transients.

Also, in order to reduce the IGBT’s power losses, the majority of IH cookers with SEPR converter use Gate voltage VGE = 18V to 21V as shown figure 10. This Gate voltage is close to the VGE maximum rating for some IGBT devices. Check for example the competitor “A” devices in figure 10, they have a 20V Gate voltage maximum rating only; too low for the typical Gate voltage of the SEPR IH cooker.
Another IGBT parameter to take into consideration for a reliable SEPR IH cooker is the Forward Safe Operating Area (FSOA). All SEPR IH cookers have a pan detection control that detects no pan or small pan situations. The majority use the single pulse method, shown in figure 11, for the pan detection. Basically, this method detects the number of resonant pulses to decide a no pan situation on the cooker. Under this method, a large peak current is generated when the IGBT is not fully ON as shown figure 11. This event occurs as well at the power startup and in both cases this is due to the initial charge of the resonant capacitor. Because of this, some manufacturers undertake special qualification procedures for the IGBTs such as reproducing the pan detection pulse for millions of cycles. In addition, with regards to the FSOA parameter, it is common in the SEPR IH cooker to observe turn-on losses when ideally they should be zero as previously discussed. This issue significantly increases the IGBT’s power losses as shown in the waveform samples in figure 12. In this specific case, the IGBT’s power losses at 800W output power is 42% higher than 2100W where no turn-on switching losses are present. This is mainly caused due to the intrinsic variable load of the system, causing capacitor voltage not to come down to zero following resonance mostly at low power levels or to a VCE zero crossing control issue. In summary, for this specific turn-on, pan detection and power startup conditions that robust IGBT’s FSOA is important for improved SEPR IH cooker reliability.

![Figure 11: IGBT’s performance during pan detection and at power startup](image1)

**Figure 11: IGBT’s performance during pan detection and at power startup**

**Table 2: IR’s 1200V IGBTs specific for Induction heating and soft switching applications**

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Package Type</th>
<th>VCES</th>
<th>Nominal Current</th>
<th>VCES transient</th>
<th>VGE</th>
<th>VCE(ON)</th>
<th>EOFF (Hard Switching)</th>
<th>T (_{\text{max}})</th>
<th>Typical Applications</th>
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<tbody>
<tr>
<td>IRG7PH35UD11PBF</td>
<td>TO-247AC</td>
<td>120W</td>
<td>20A</td>
<td>1300V</td>
<td>+/-30V</td>
<td>1.9V</td>
<td>1120μs</td>
<td>150°C</td>
<td>IH Cooktaps</td>
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<td>IH Rice Cookers</td>
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<td>Microwave Ovens</td>
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<td>Copy Machines</td>
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![IGBT’s IC & VCE at 800W Output Power](image2)

**IGBT’s IC & VCE at 800W Output Power**

**Figure 12: Example of typical IGBT’s turn-on losses for SEPR IH cooker**

IR’s 1200V Devices Specific for IH and Soft Switching Applications

In summary, the proper selection of the IGBT device’s key parameters results in a very efficient and reliable SEPR IH cooker. By following these guidelines, IR has released two 1200V IGBT Copack devices specific to IH cooker’s requirements, optimizing the key parameters for best performance and enabling lower cooker’s power losses. Their improved ruggedness with parameters such as guaranteed 1300V transient voltage capacity, 30V VGE rating, and robust FSOA, reduce or even eliminates the impact of typical field failure issues improving the cooker’s reliability.

References


PCIM Booth 11-111

www.irf.com