The 650 V Reverse Conducting R6 family for induction heating and resonant applications

About this document

Scope and purpose

This application scope is intended to give an insight into the 650 V Reverse Conducting R6 family of IGBTs, which are specially developed for induction heating (IH) applications that are based on a half-bridge topology.

Induction heating applications comprise many segments of the industry, including consumer and industrial environment. The main target of the 650 V Reverse Conduting R6 family is the induction cooking application, which is mostly used in domestic environments, and to some extent in professional environments, e.g. restaurant kitchens. To address consumer applications poses many challenges, as the consumer market is strongly price-driven and very competitive. However, at the same time it needs to comply with governmental regulations to reduce energy consumption and electromagnetic noise. For this reason, the devices which target this market have to be designed with the best trade-off in terms of price and perfomance.

Especially in terms of system performance, the right selection of a suitable IGBT is necessary. Therefore, Infineon Technologies offers a broad portfolio of IGBTs for IH appliances to cover different system requirements. The new 650 V Reverse Conducting R6 IGBTs are suited for a half-bridge induction cooking topology, and are offered in the current classes 30 A (IHW30N65R6), 40 A (IHW40N65R6), and 50 A (IHW50N65R6) to help users select the right IGBT for their target application.

Intended audience

This application note is intended for those who would like an introduction to the discrete 650 V Reverse Conducting R6 family.

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Introduction

1.1 Instructions

The following information is provided as a reference for the implementation of the device, and is not to be regarded as a description or warranty of a certain functionality, condition or quality of the device. This application note is intended to describe the general improvements and benefits of the 650 V Reverse Conducting R6 discrete IGBT family. It provides background information for designers of power electronic systems as well as details concerning the benefits of designing discrete devices in consumer applications.

1.2 650 V Reverse Conducting R6 overview

Infineon Technologies has developed the 650 V Rreverse Conducting R6 IGBT technology with the aim to improve the system performance of half-bridge induction cookers. The device is based on Infineon's well-established reverse-conducting (RC) IGBT technology, which is optimized for the soft-switching operations typical of a half-bridge IH topology. Offered in the standard TO-247 3-pin package, like the previous 650 V R5 generation, the device is compatible with existing designs. Figure 1 shows the overall portfolio of Infineon discrete IGBTs for the induction cooking application. Similar to other RC-IGBTs from Infineon, the 650 V R6 incorporates a monolithically-integrated, reverse-conduction freewheeling diode, thus eliminating the need for a separate diode that is usually co-packed with the IGBT. Whilst the RC-IGBT is not a new concept in the IH platform, it is not very well-known in the 650 V area. In this case, the 650 V R6 device from Infineon represents a unique case in terms of electrical performance within the reverse-conducting IGBT landscape.

I_c nom [A]	Features	Price		Performance			Protection
	Topology	Single ended	Half-bridge	Single ended			Single ended
	Family	E1	R6	R5	R5	R5	IPD
	Voltage	1200V	650V	1200V	1350V	1600V	1350V
15		IHW15N120E1					
20				IHW20N120R5	IHW20N135R5		IEWS20R5135IPB
25		IHW25N120E1					
30			IHW30N65R6	IHW30N120R5	IHW30N135R5	IHW30N160R5	
40			IHW40N65R6	IHW40N120R5	IHW40N135R5		
50			IHW50N65R6				
Package		TO247-3	TO247-3	TO247-3	TO247-3	TO247-3	TO247-6
Recommended driver IC		IRS44273L	2ED21844S06J	IRS44273L	IRS44273L	IRS44273L	Co-packed driver with protection functions

Figure 1 Infineon IGBT and gate driver portfolio for induction cooking application. 650 V R6 family is highlighted.

1.3 Application description

Induction cooking systems are usally built with two different topologies that are based on resonant topologies due to their lower conversion losses and lower emission of interferences.

Together with the single-ended parallel resonant (SEPR) converter, the half-bridge series resonant (HBSR) converter, shown in Figure 2, is one of the two topologies that can be used for IH appliances. In comparison to

the SEPR topology, the half-bridge converter offers several advantages. These include better controllability of the cooking power, higher maximum output power, and lower and more stable bus voltage at all output power levels, as the IGBTs are operated directly from the rectified line. It also offers the advantage of operating the system continuously at lower power levels without the risk of changing to hard-switching operation. Therefore, in terms of system reliability and performance, the HBSR converter is the preferred choice over the SEPR topology. For a detailed description about the operation of the resonant converter for induction cooking, refer to [1].

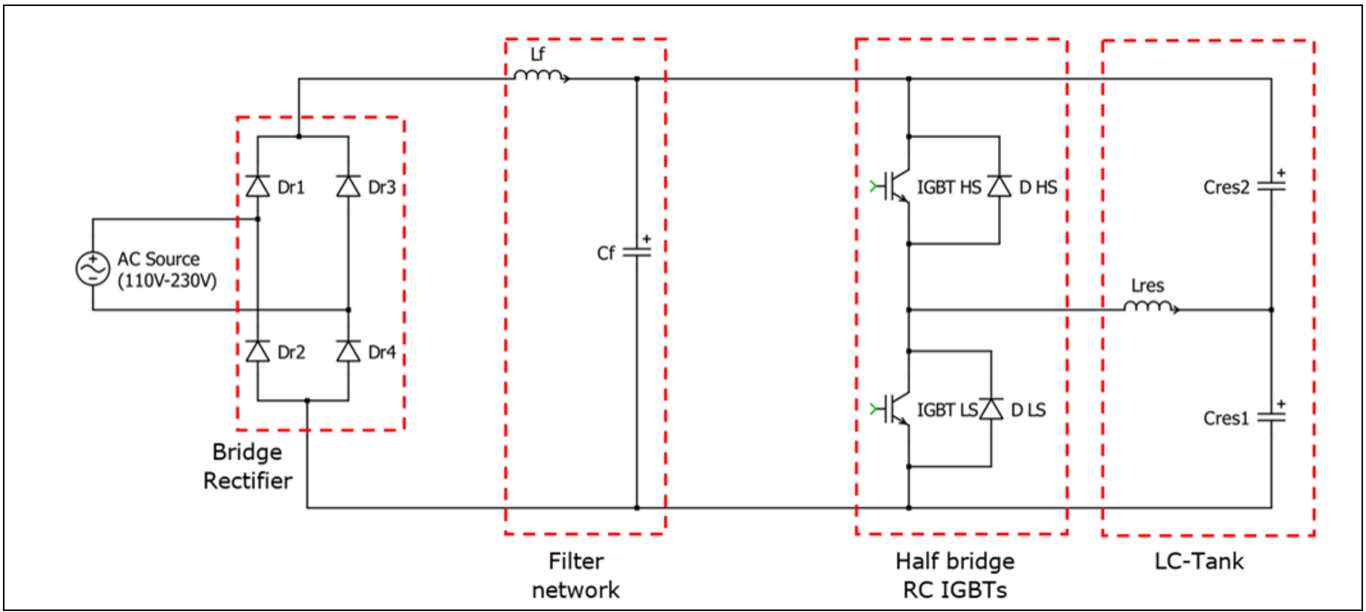


Figure 2 **Schematic of the half-bridge converter.**

2 Product benefits

2.1 Improvement in IGBT performance

The 650V Reverse Conducting R6 offers very good performance in terms of V_{CEsat}, diode conduction losses and IGBT switching losses, which are known as the main contributors of power device losses in the half-bridge IH topology.

In particular, the R6 technology has been developed as an improvement of the previous 650 V R5 generation. The main improvements of the 650 V R6 technology compared to the 650 V R5 are the lower V_{CEsat} and the reduced V_F. Since the main contribution to total IGBT power losses comes from the conduction losses of the device, the V_{CEsat} in the new R6 generation has been reduced by approximately 50-90 mV (depending on the current class of the device). This can be seen in Figure 3, where the orange line depicts the V_{CEsat} for the R6 technology in comparison to the previous R5 technology in blue.

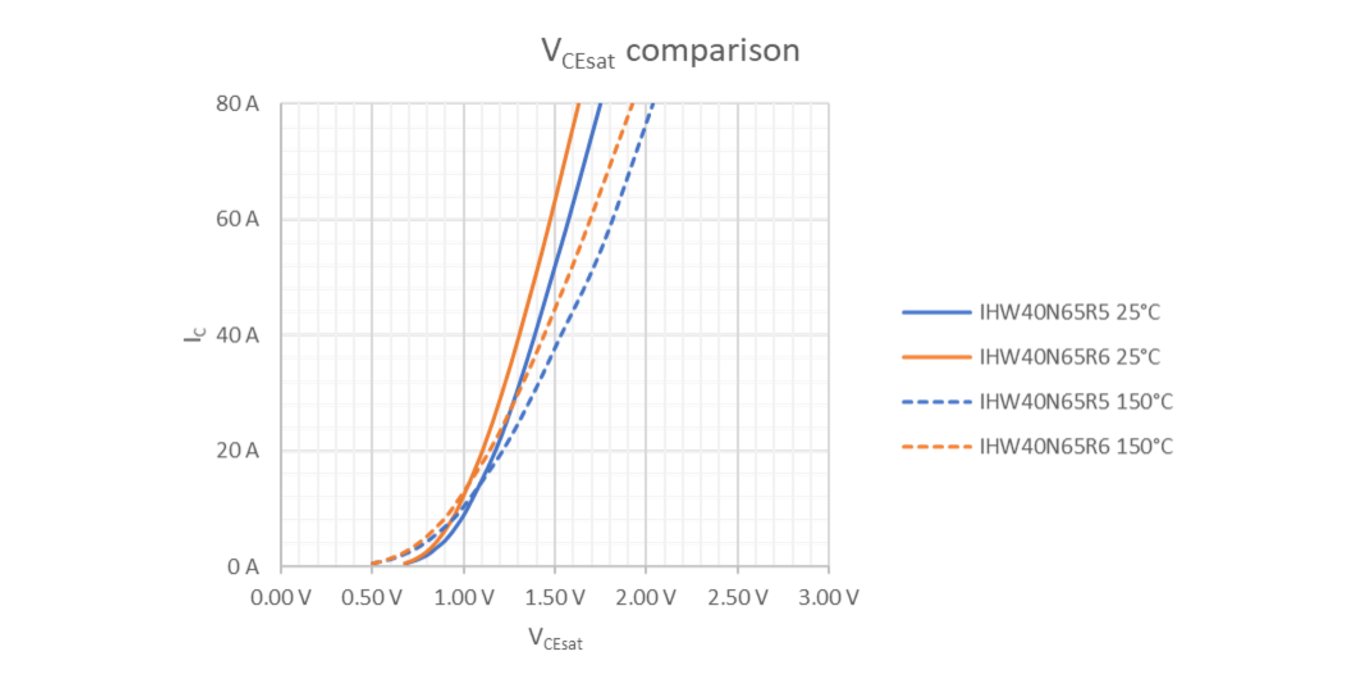


Figure 3 Comparison of V_{CEsat} for R6 and R5 technology.

Another improvement in terms of the IGBT is that the turn-off operation of the IGBT has been softened in order to reduce the impact of electro-magnetic interference (EMI) in the system performance. As shown in Figure 4, the 650 V R5 waveform in turn-off shows a glitch on the VCE voltage due to a rapid decrease of the collector, which resonates with the snubber capacitance. This voltage glitch produces a localized peak in the frequency spectrum, whose position depends on the value of the snubber capacitance (usually it falls in the range of 30 MHz). In the R6 waveforms, the tail current decrease has been made smoother, thus eliminating the glitch and consequently improving the EMI behavior. It should be noted that the switching losses of the R6 are slightly higher due to the longer tail current. However, the impact on the overall power losses is negligible, as shown in section 2.3.

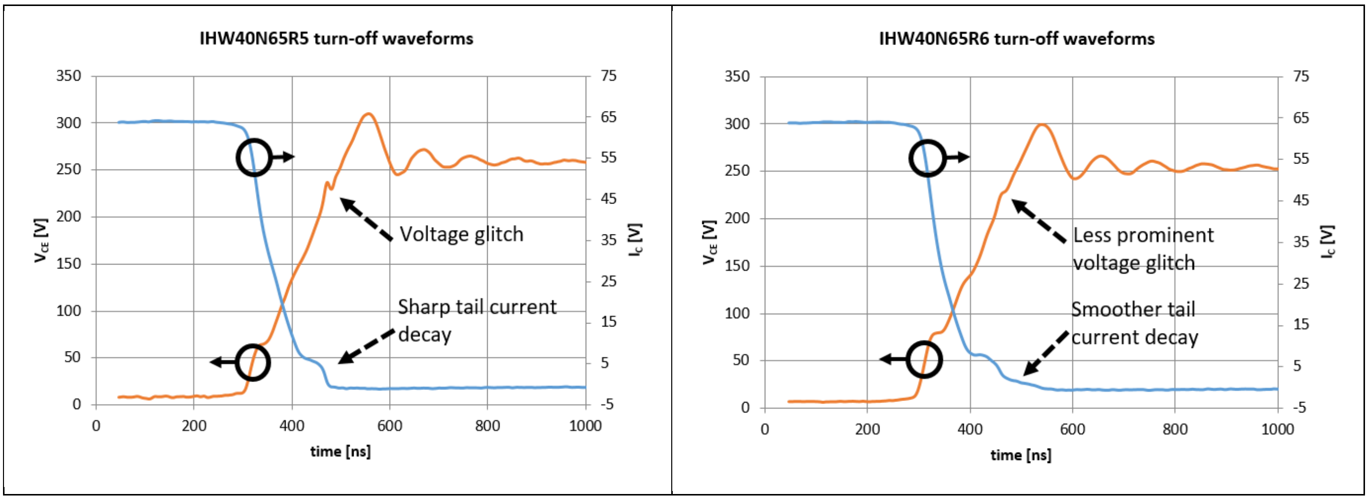


Figure 4 **Comparison of turn-off waveforms of IHW40N65R5 and IHW40N65R6.**

2.2 Improvement in diode performance

Diode performance is also important, especially in cases where low-resistive cooking vessels are used, which cause high reactive currents. However, for most practical cases, where proper cooking vessels are used, the major portion of the losses of the active device are normally related to the conduction losses of the IGBT. The biggest improvement from the R5 to the R6 generation has involved the diode, whose forward voltage VF has been significantly reduced, with a consequent reduction of its conduction losses, as can be seen in Figure 5. The forward voltage of the R6 diode has been reduced by approximately 200 mV at 25°C, and the improvement is even higher at 150°C. This means that the device is more temperature-stable, and that the diode conduction losses do not increase significantly due to higher temperature in the application, which lessens the impact of temperature on the diode power losses.

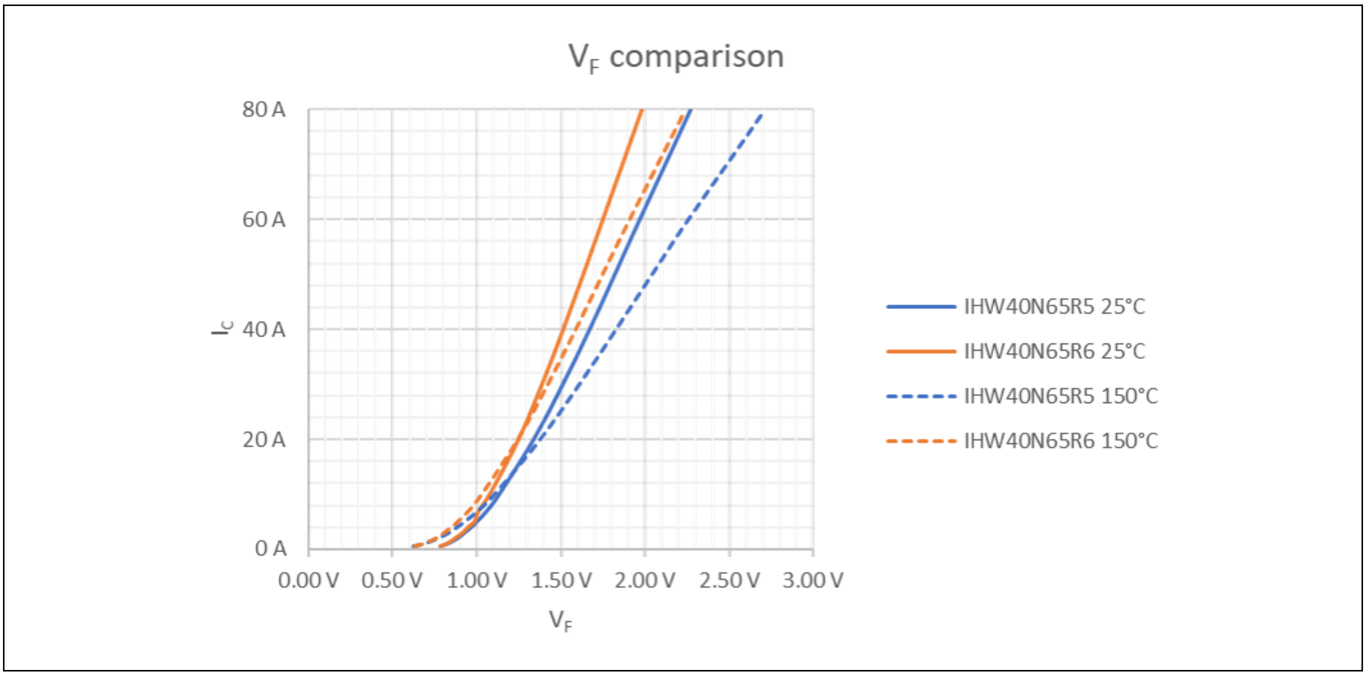
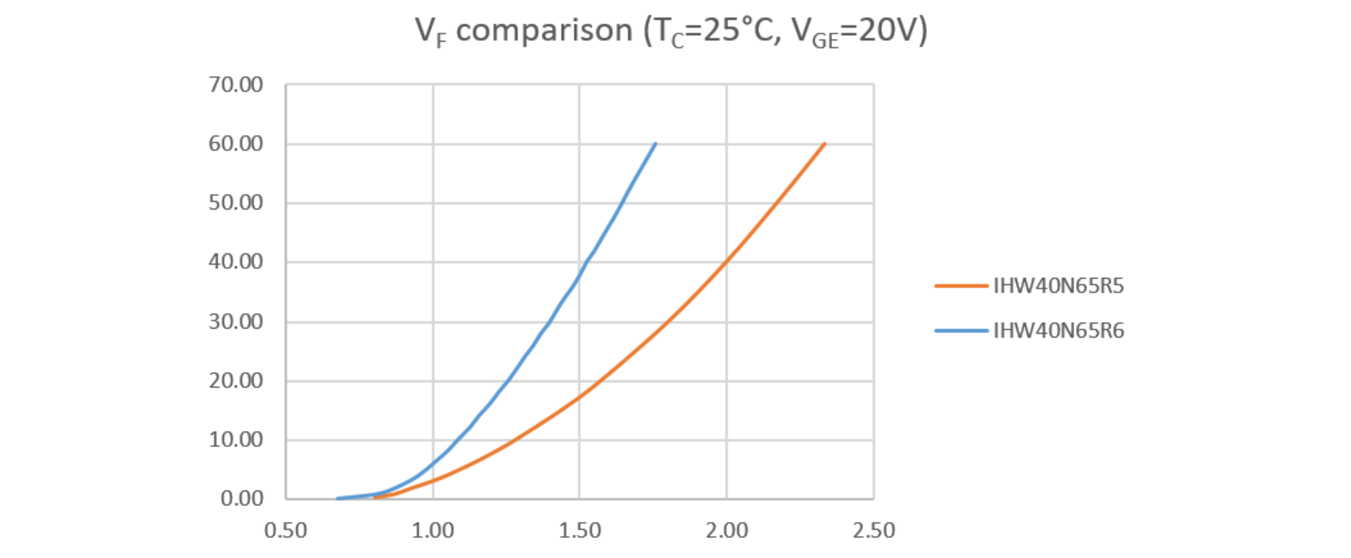


Figure 5 **Comparison of V_F for R6 and R5 technology.**

The improvement of the R6 diode also regards the effect of the VGE voltage on the diode forward voltage. As shown in Figure 6a and Figure 6b, the forward voltage of the R5 diode increases significantly when 20 V are applied between gate and emitter terminals, although the difference of is almost negligible for the R6. At 40 A, as an example, the IHW40N65R5 has a VF variation of 350 mV, while the IHW40N65R6 has only 20 mV. This effect is quite relevant in the application, as there are cases where the diode conduces when the IGBT VGE is high, especially with high inductive loads. So the R6 diode performance is expected to be even more relevant in real application conditions.



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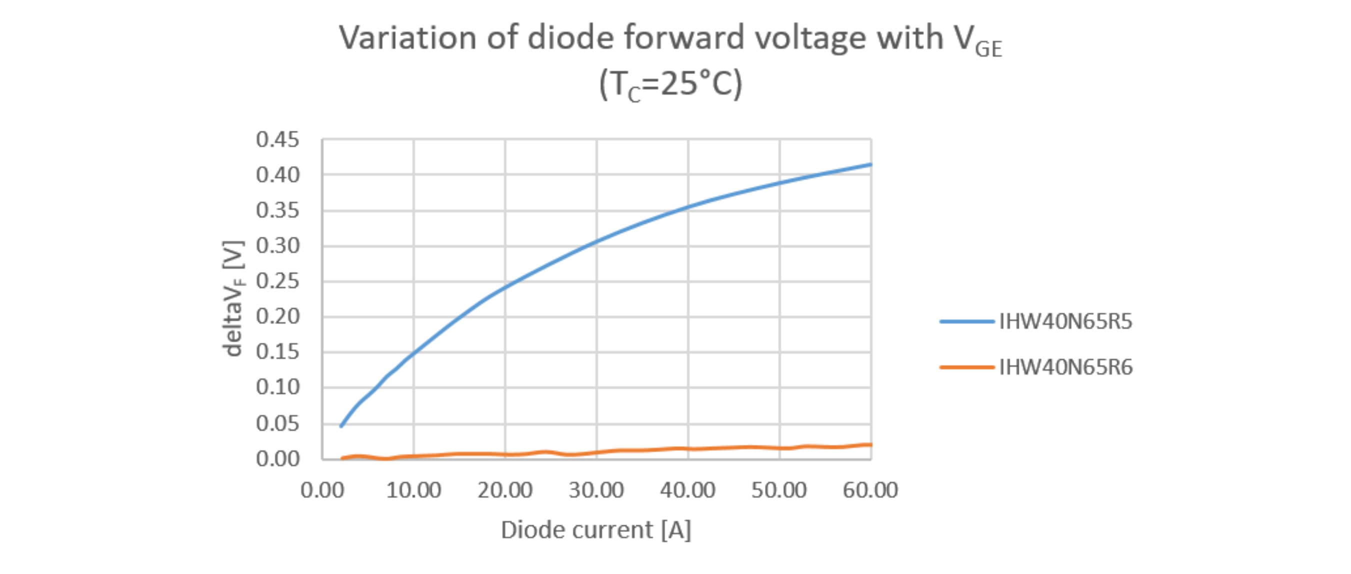


b)

Figure 6 Comparison of V_F variation with V_{GE}=0V and V_{GE}=20V for R6 and R5 technologies (T_C=25°).

Finally, a last improvement in the diode has involved its turn-on behavior, which is commonly referred to as forward recovery. In an ideal diode, as soon as the current starts to flow, the voltage immediately reaches the static value corresponding to the particular current. In a real diode, on the other hand, the voltage increases temporarily to a higher value before reducing to the static VF, as illustrated in Figure 7. This is due to the fact that a certain time is needed to build up the charge in the diode structure, thus to reach the maximum

electrical conductivity. In general, the amplitude (V_{FRM}) and the duration (t_{FR}) of the overvoltage during the forward-recovery phase is directly correlated to the forward voltage of the diode. For a given diode, the negative effects of forward recovery are intensified by the speed of the current increase in the diode. In addition, in the case of monolithically integrated diodes, the phenomenon of forward recovery is partially exacerbated due to the particular structure of the device.

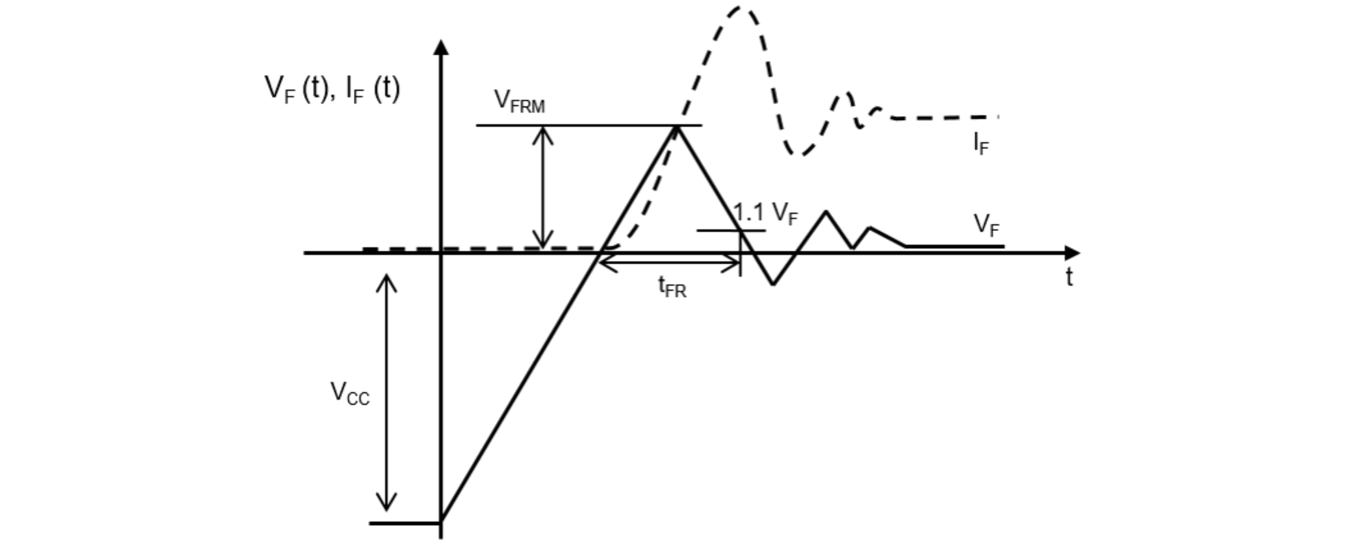


Figure 7 **Schematic representation of the forward-recovery voltage of a diode.**

Keeping the diode overshoot amplitude and time duration to reasonably low values is of particular relevance in the half-bridge topology, as high diode overvoltages can lead to a failure in the driver stage, especially when driver ICs with junction-isolation technologies are used. This is due to the negative transient of the floating reference supply of the gate driver (node Vs), as shown in Figure 8. If the negative voltage at node Vs is too high, the functional isolation of the gate driver might be exceeded, thus injecting current in the driver substrate, and eventually leading to failure [2]. In addition, even if the driver is robust in terms of high negative voltage transients of node Vs, another harmful effect can occur. The bootstrap capacitance can be charged to a value higher than the supply voltage, thus increasing the V_{GE} of the high-side IGBT during the turn-on phase.

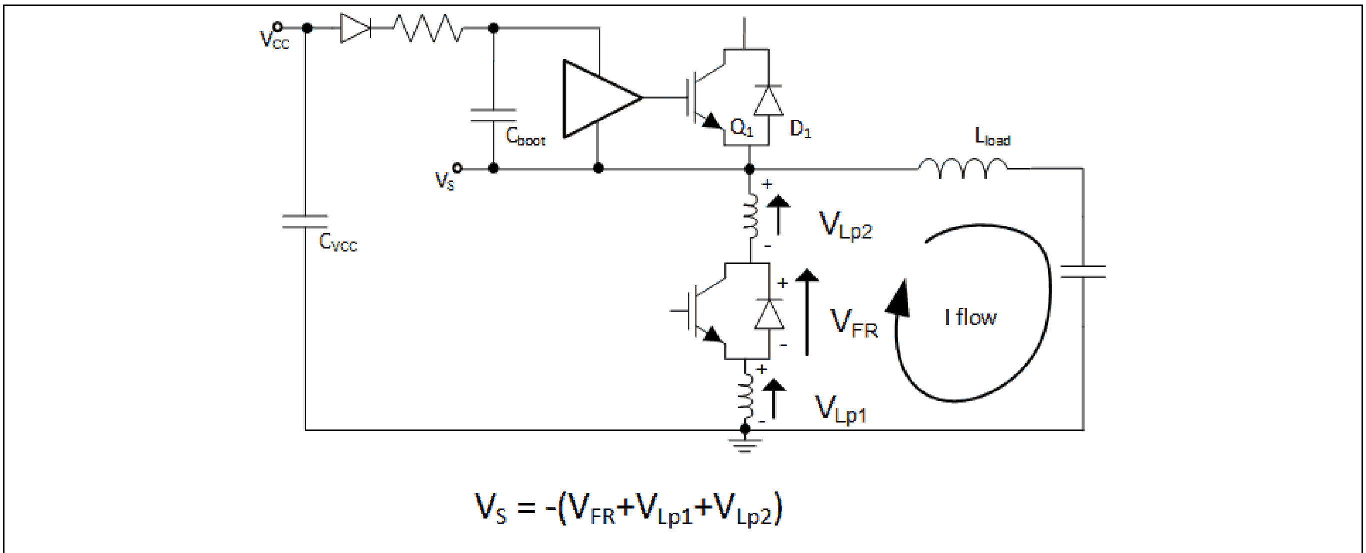


Figure 8 **Impact of turn-on diode behavior on the floating supply pin of a level-shift gate driver.**

For the reason explained above, the diode forward recovery has been significantly improved in the 650 V R6 technology with respect to the previous R5 generation. Figure 9 shows a typical diode turn-on waveform, when a snubber capacitor of 10 nF is places in parallel to the high-side IGBT; Table 1 shows the comparison between the diode turn-on behavior of the IHW40N65R6, the IHW40N65R5and the IKW50N65ES5 measured according to the circuit of Figure 8. The IKW50N65ES5 has a separate diode co-packed with the IGBT and therefore it represents the benchmark for both the R6 and the R5 technology. As can be seen, the amplitude of the diode overvoltage is reduced in the R6 device by roughly 30%. Furthermore, the IHW40N65R6 diode performs almost as well as the one of the IKW50N65ES5.

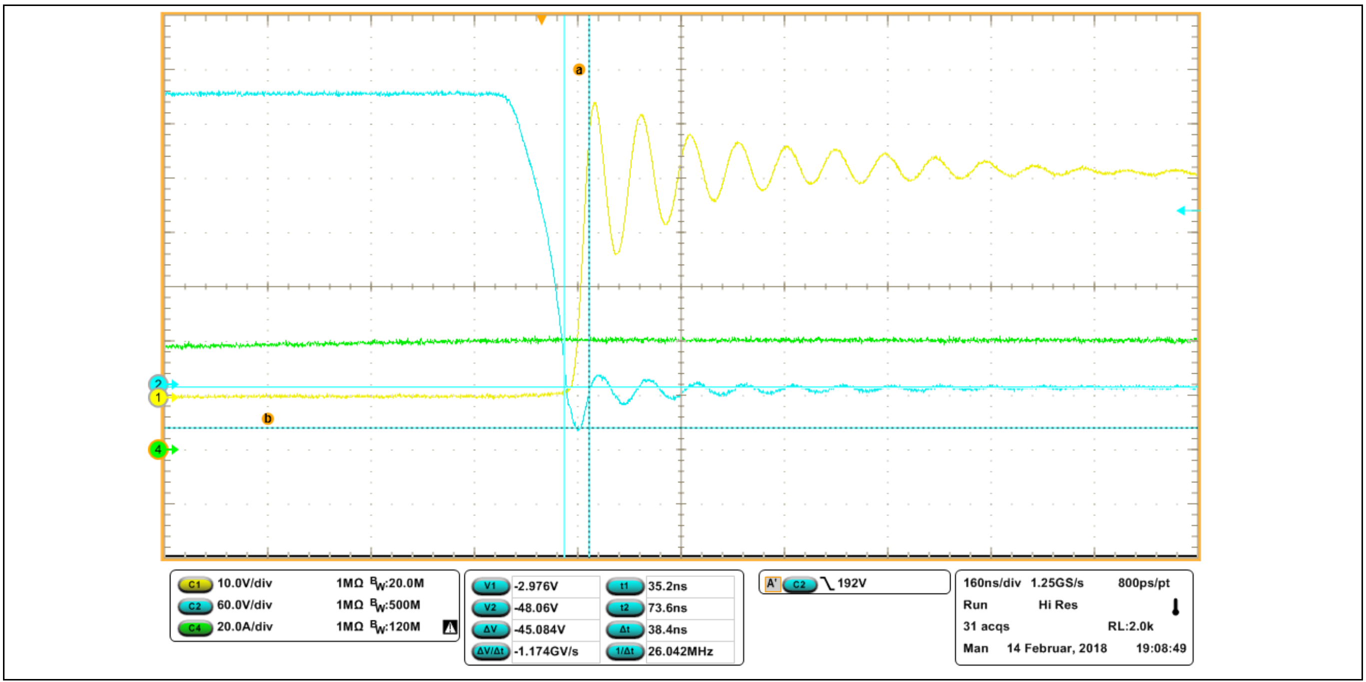


Figure 9 Typical diode turn-on waveform, measured according to the circuit in Figure 8.

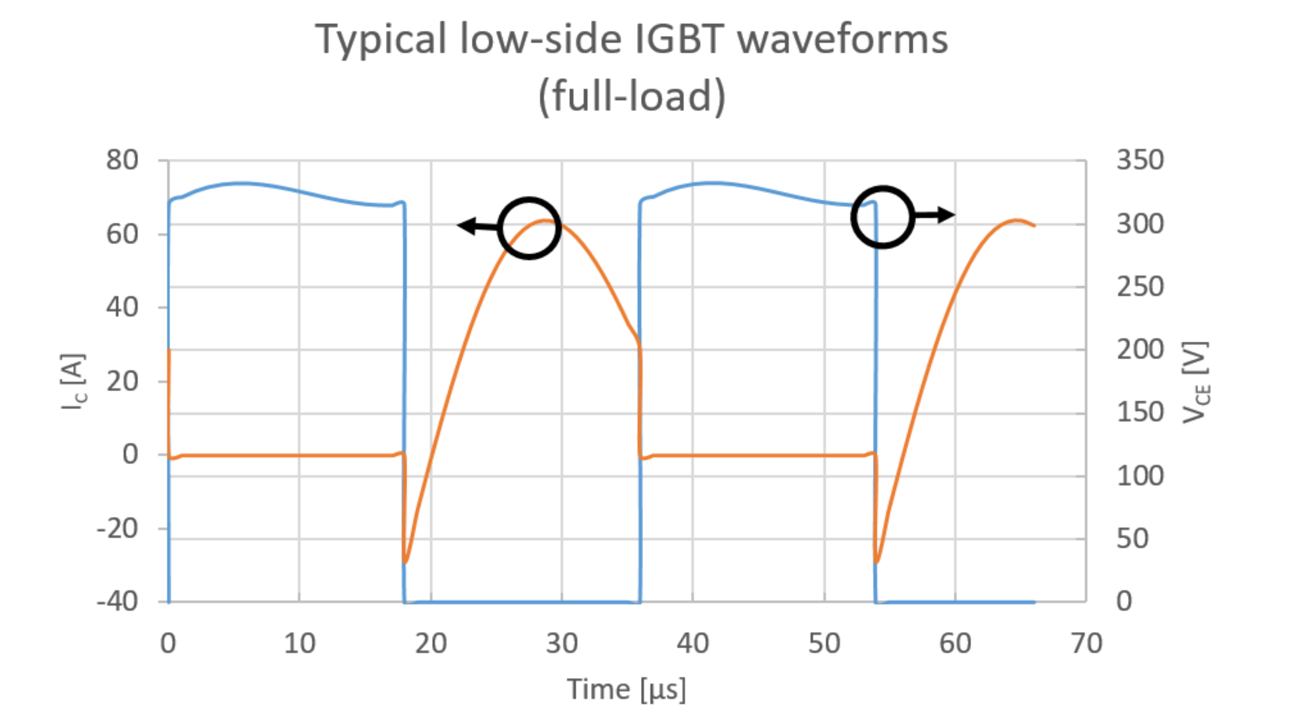
Table 1

Device	**Diode technology**	**V_{FRM} [V]**	**t_{FR} [ns]**
IHW40N65R6	Reverse-conducting IGBT with monolithically integrated diode	80	60
IHW40N65R5		110	60
IKW50N65ES5	Standard IGBT with co-packed standalone diode	72	55

2.3 Effects of device improvements on power losses in the applications

The improvements shown in the previous sections contribute to different extents to the overall IGBT losses during typical operating conditions of a half-bridge series resonant converter. The typical waveforms in the case of high-load operation (that is, close to the resonant frequency of the inverter) are depicted in Figure 10a. In these conditions, the IGBT conducts for almost half of the switching cycle, and it turns on and off almost at zero current. On the other hand, the diode conduction time is much shorter than that of the IGBT, and is usually limited to 1 to 2% of the total switching period. As a consequence of this operating mode, the IGBT conduction losses have the strongest contribution to overall device losses, accounting for roughly 80%, as shown in Figure

10b. From the figure, it can also be seen that the 40 A R6 performs better than the 40 A R5, due to the reduced V_{CEsat}, and can even be considered as a replacement for a 50 A R5.



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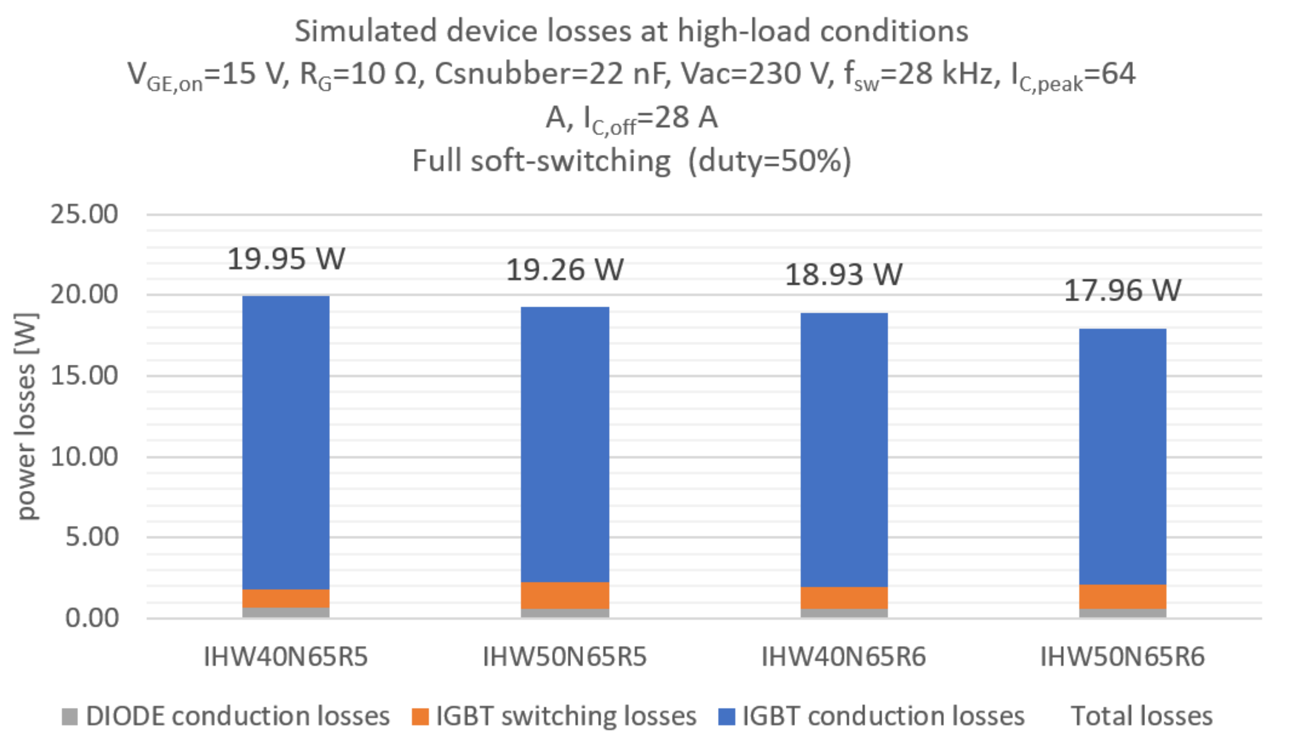
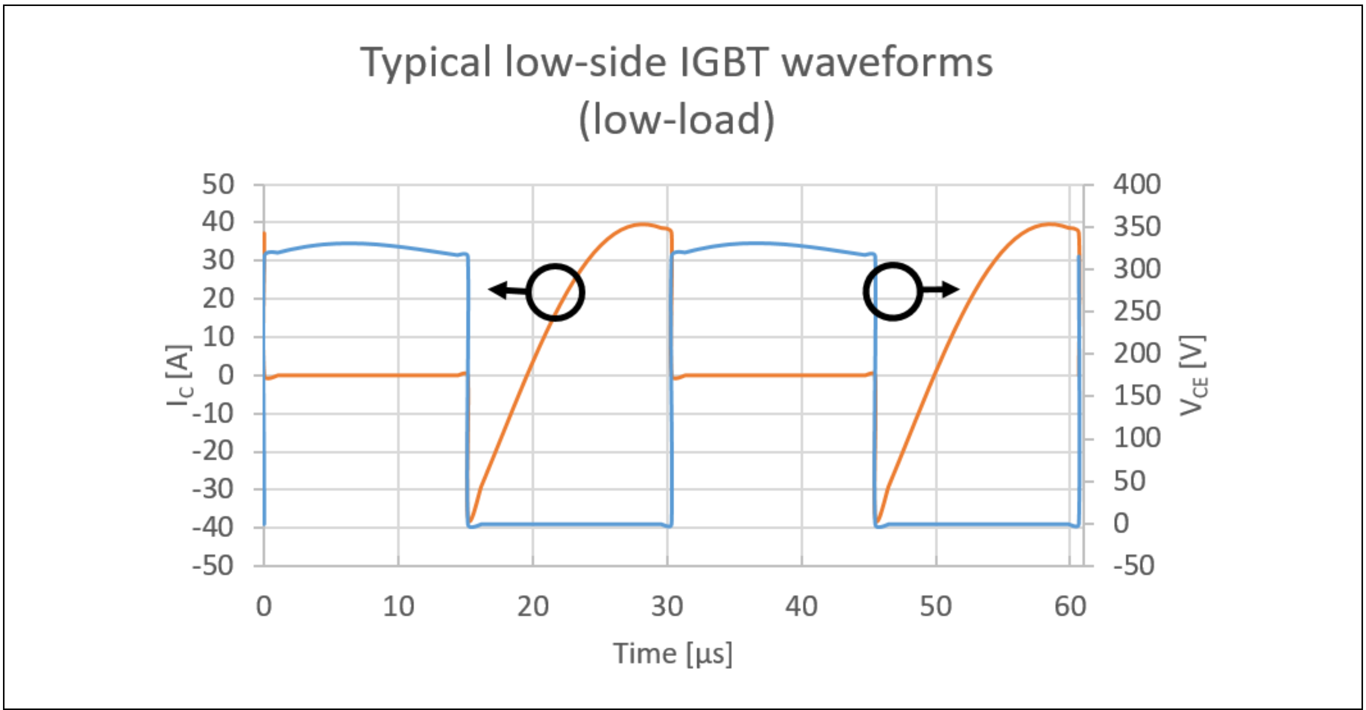


b)

Figure 10 **a) Typical IGBT waveforms in high-load operation; b) simulated IGBT power losses (conditions as indicated in the figure).**

At lower power conditions, which usually correspond to higher switching frequencies, the diode conduction time increases, as well as the IGBT turn-off current, as shown in Figure 11a. As a consequence, the switching losses of the IGBT and the conduction losses of the diode become more relevant, although IGBT conduction losses remain more dominant. In these lower power conditions, the 650 V R6 technology can benefit also from the improved diode conduction losses. As mentioned before, the switching losses of the R6 are slightly higher than the R5 due to the softer turn-off behavior of the first. However the impact on the overall power dissipation is almost negligible. The comparison of R6 and R5 device losses in low-load operating conditions are shown in Figure 11b. In low-load operation, the swithing losses account for roughly 23% of the total losses.



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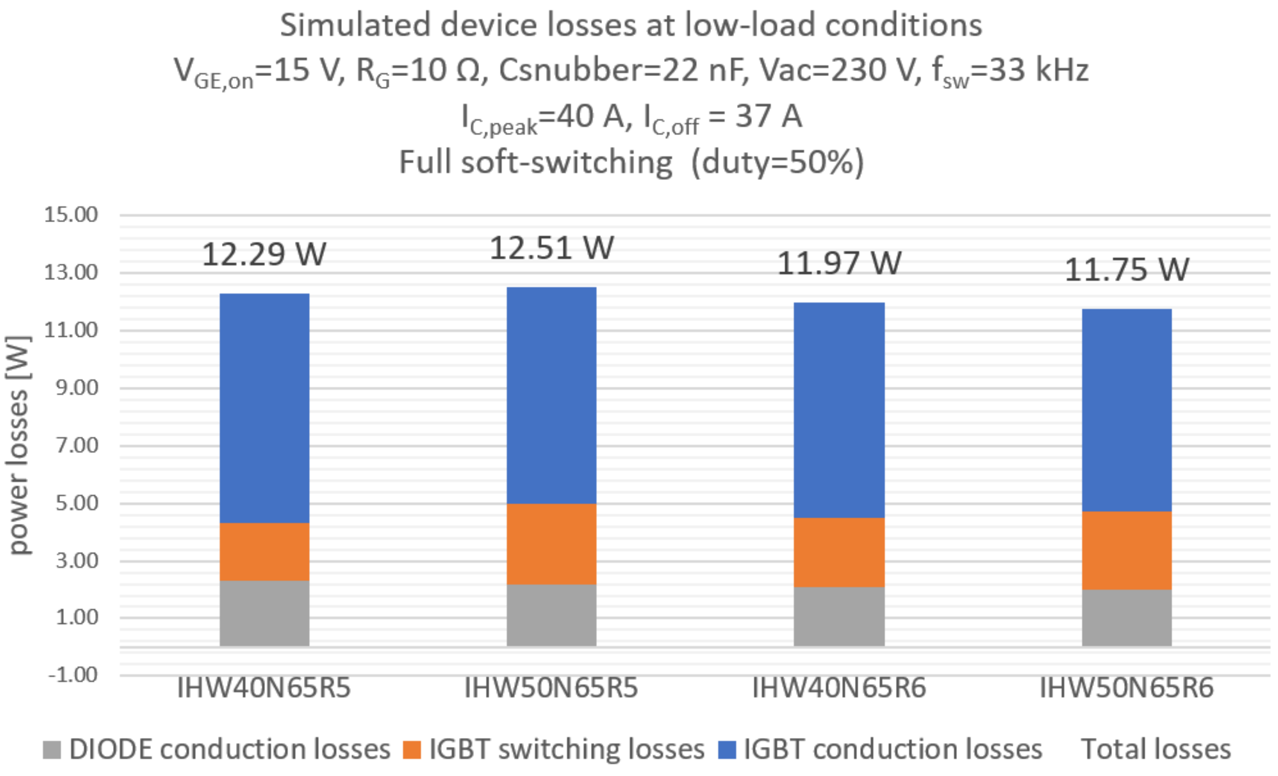


b)

Figure 11 a) Typical IGBT waveforms in low-load operation; b) simulated IGBT power losses (conditions as indicated in the figure).

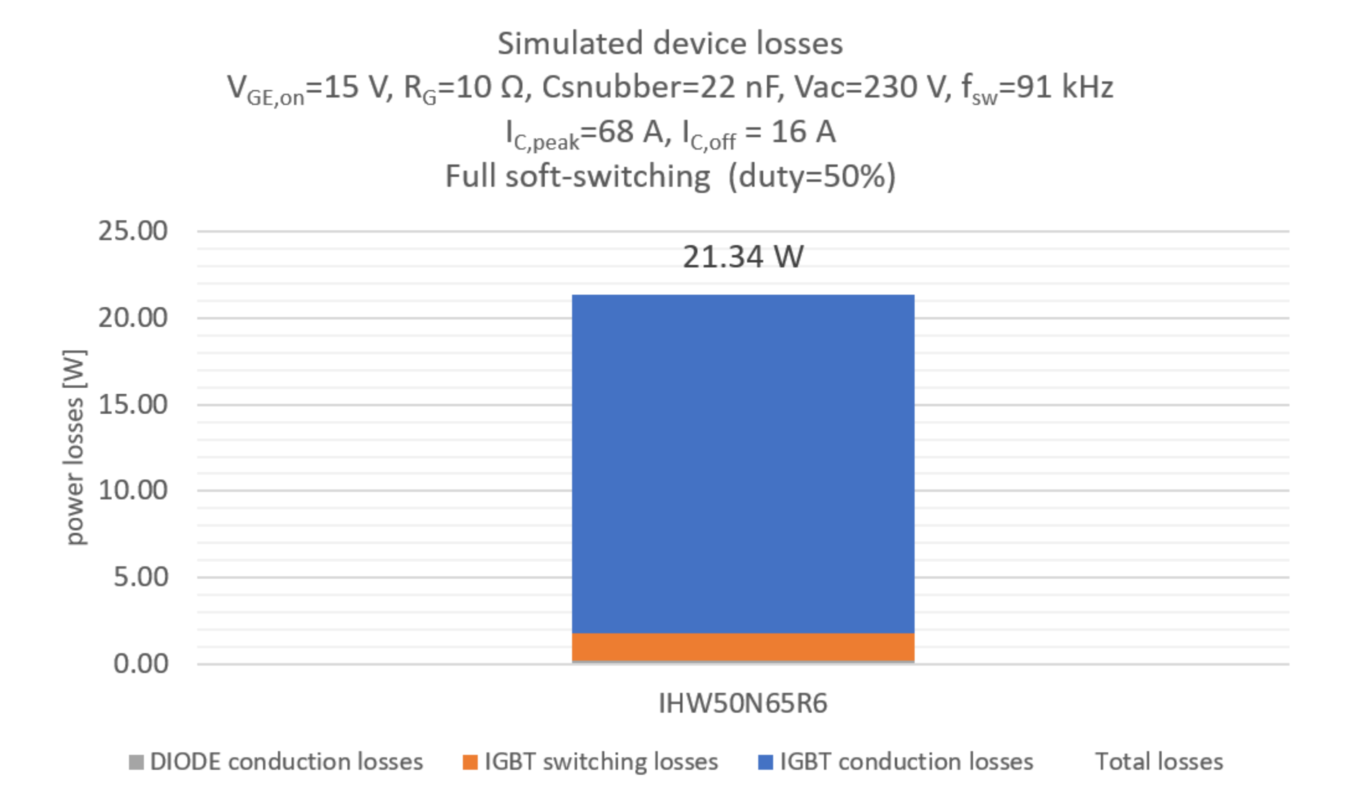
From the comparison of Figure 10 and Figure 11, it can be noted that the power losses of the device are higher in high-load operation. For this reason, as already mentioned, the main improvement of the 650 V R6 technology over the previous 650 V R5 generation is represented by the reduced V_{CEsat}.

2.4 Using 650 V R6 for high switching frequency designs

The switching frequency of a half-bridge based induction cooker is typically in the range of 25 – 30 kHz in the highest output power operation. Moving to higher switching frequencies has not been considered advantageous for induction cooking applications so far, mainly because the size of the inductor is determined by the typical size of the cooking pots. However, there are examples in the markets that experiment with higher switching frequencies, for example, to enable the induction technology to operate with different pot materials ([4], [5]). For these examples, the switching frequency in high-load condition can rise to more than 100 kHz, which is usually considered the limit for IGBT operation, due to its inherent high switching losses compared to power MOSFETs for instance. However, the relatively low soft-switching losses of the 650 V R6 family also make it suitable for operation with systems in the range of 100 kHz. An estimation of power losses of the 650 V, 50 A R6 was therefore carried out in a HBSR inverter with a resonant frequency of 89 kHz. Figure 12 shows the results of the estimation, in which:

- the top figure shows the expected power losses when the IGBT operates at 90 kHz, i.e., with an output load that is roughy 95% of the maximum output power;
- the bottom figure shows the expected power losses when the IGBT operates at 106 kHz, i.e., with an output load that is roughly 30% of the maximum output power.

As shown, the losses of the IHW50N65R6, even at 106 kHz and a turn-off current of 34 A, account for 38% of the total losses; hence, the impact on the overall device losses is not significantly higher than in the case of operation at lower switching frequencies.



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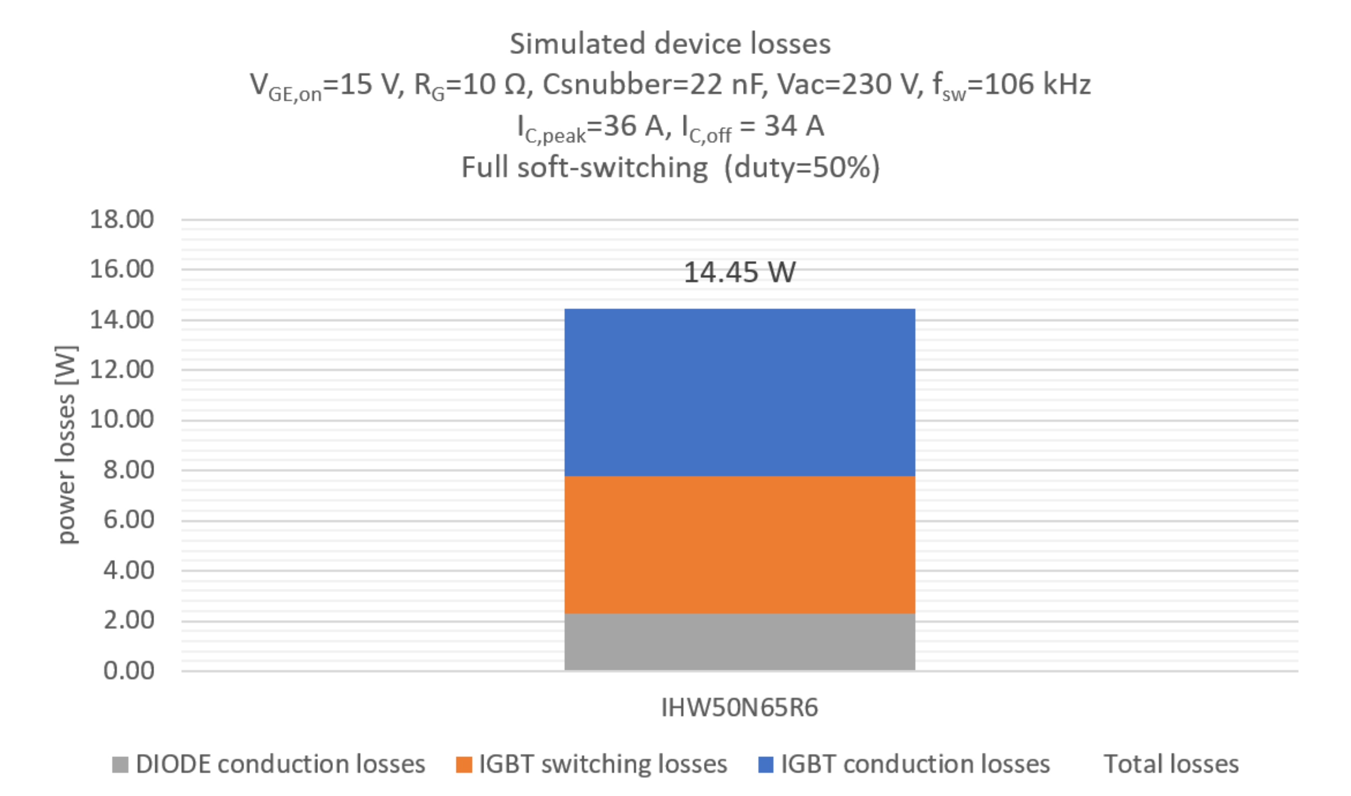

b)

Figure 12 Simulated IHW30N65R6 IGBT power losses for high-frequency operations: a) 90% output load, b) 30% output load.

2.5 Gate driver IC selection for 650 V R6 family

All the 650 V R6 IGBTs are ideally paired with the 650 V SOI gate driver ICs such as 2ED21844S06J. These gate driver ICs offer important features including:

- Negative VS immunity up to -100 V
- Integrated ultra-fast, low-resistance bootstrap diode
- Integrated shoot-through protection and built-in dead time
- Maximum supply voltage of 25 V
- Low-level shift losses

In particular, for IGBTs with an IC above 30 A, it is recommended to use ICs in the DSO-14 package. Starting from this power level, it is helpful to have separate grounds for logic (VSS) and power (COM).

3 Conclusion

The new Infineon R6 IGBT family represents the best choice for half-bridge IH appliances with switching frequencies up to 80 kHz, and offers the best performance for all high-end systems. With the R6 IGBT series, Infineon now offers an RC IGBT which has increased performance and lower power losses in the application compared to the previous generation.

4 References

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