

**New trench gate field-stop V series:
the real tail-less IGBT**

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Introduction

Based on an advanced proprietary 600 V trench gate field-stop (TGFS) structure, the V series of IGBTs reveals the lowest switching energy in the world.

Featuring tail-less switching-off waveforms and co-packing an ultra-fast freewheeling diode tailored to very low switching energy losses, this revolutionary technology offers several benefits in high switching frequency applications demanding superior efficiency, such as: PFC, welding machines, solar inverters, induction heaters, UPS and so any high voltage DC-DC converter.

The V series of IGBTs from ST also guarantees 175 °C as max. junction temperature, with a further increase of the reliability and lifetime of the device.

The series current rating ranges from 20 A to 80 A with a safe paralleling operation for higher power needs.

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1 Overview

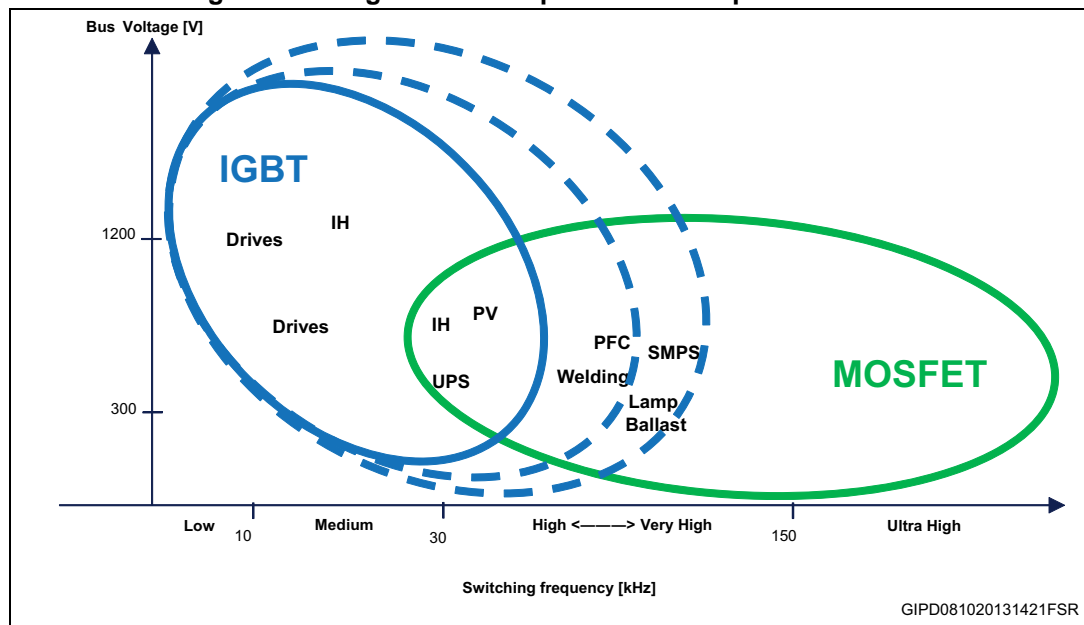
The demand of very high efficiency standards together with cost competitiveness is the main reason why operative frequency rises in energy-conscious equipment.

New IGBT technologies are gaining more and more market share in power switches thanks to the advantages in high power density (or smaller die size for a given power requirement), dynamic performance continuous improvement and, a freewheeling diode specifically tailored to any request of applications. This reduces the gap between IGBT and MOSFET in high frequency applications (*Figure 1*).

This article aims to present the furthest IGBT series ever released in the market as the best power device solution for high-speed applications.

This article describes how these specific advantages have been obtained, by analyzing both static and dynamic behavior, compares the overall performance between V series and what the best competition offers in high-speed series. Two benchmark analyses, carried out on a welding machine and on an induction heating system, conclude this article and give clear evidence about the V series efficiency for high frequency applications.

Figure 1. Voltage controlled power switch operative areas



2 V technology features

In order to reduce the overall power loss caused by switches, three main features of this V series allow the best compromise between static and dynamic behavior:

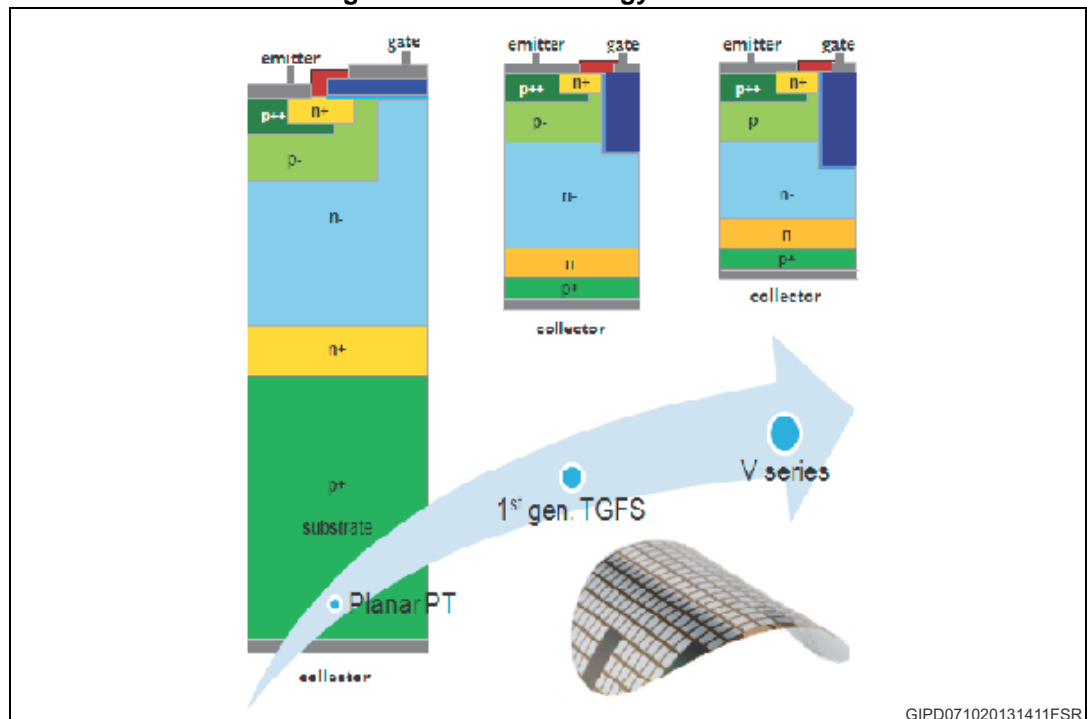
- the reduced die thickness, without losing safe limit for device reliability, allows a significant reduction of minority carriers within the drift zone. Therefore, it enhances the switching performance and lowers the transistor's thermal resistance.
- the optimization of the PNP bipolar output stage improves further the dynamic behavior of the device.
- the increased trench gate depth gets higher current density and lowers the conduction loss when switch is on.

Thanks to this superlative efficiency, the power device works at a cooler temperature, improves the overall application reliability and simplifies the design of thermal management such as heat-sinks or cooling fans. The maximum junction temperature guaranteed by this new technology has been raised to 175 °C.

In order to fulfill any request of freewheeling function, a tailored anti-parallel diode option co-packed with the IGBT is proposed for different switching conditions (a low-drop version for soft switching instead of an ultra-fast one for hard switching), minimizing the loss due to diode.

Furthermore, ST's manufacturing process for the TGFS technology ensures tight control over parameters such as the $V_{CE(sat)}$. Combined with a slightly positive temperature coefficient of saturation voltage, this feature makes parallel connections safer when high power applications are being built.

Figure 2. IGBT technology evolution



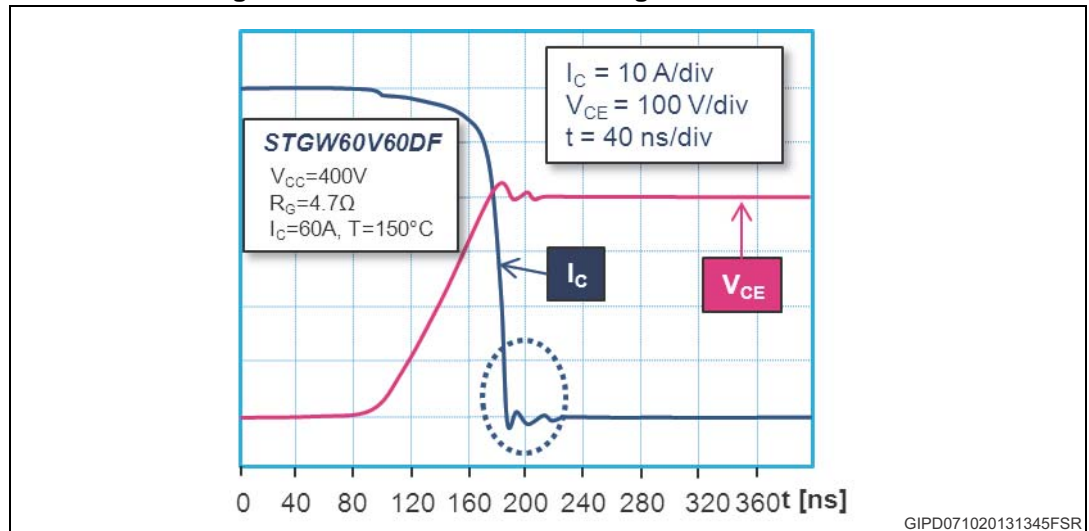
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2.1 Static and dynamic performance

In order to analyze how these technology improvements translate into electrical performance of the V series of IGBTs, the 60 A (@ 100 °C) size results have been taken as champion family; other devices of different sizes, belonging to the V series, have the same behavior at their own nominal current.

Figure 3 shows the tail-less switching-off waveforms of the collector current.

Figure 3. STGW60V60DF switching-off characteristics

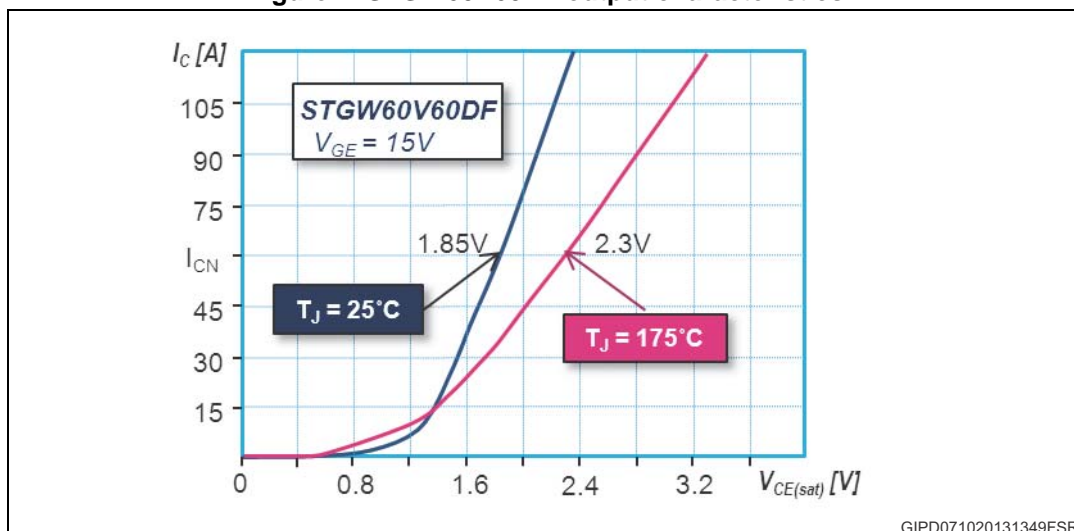


The "MOSFET-like" switching-off behavior has never been experienced in an IGBT so far, whose tail current represents the main limitation in very high frequency applications. On contrary, it is the reason why the V series reveals the lowest switching-off energy in the worldwide market as a real breakthrough in this power transistor application range.

Moreover, this significant reduction of dynamic losses does not cause any voltage overshoot or ripple emphasis that might be expected as drawback of the high switching speed, even driving with low values of gate resistor. Therefore no extra design effort is required for EMI limitation, in fact, the switching loss reduction is given mainly by the tail-less behavior of the current fall (when voltage is high), while the transient remains soft.

Figure 4 shows the STGW60V60DF output characteristics, having 1.85 V on voltage drop at room temperature; despite of the switching speed rise, static performance has been reduced by 50-100 mV versus the previous TGFS technology generation.

Figure 4. STGW60V60DF output characteristics



3 V series electrical positioning

Figure 5 shows the electrical positioning of the V series. The main competitors' same current rated devices, the first TGFS technology previously released by ST and the V series are compared.

Based on specifications at room temperature and nominal current conditions, the V series reveals the best trade-off between statics and dynamics, and specifically the lowest switching-off energy, which is the major contribution to total losses in high frequency applications.

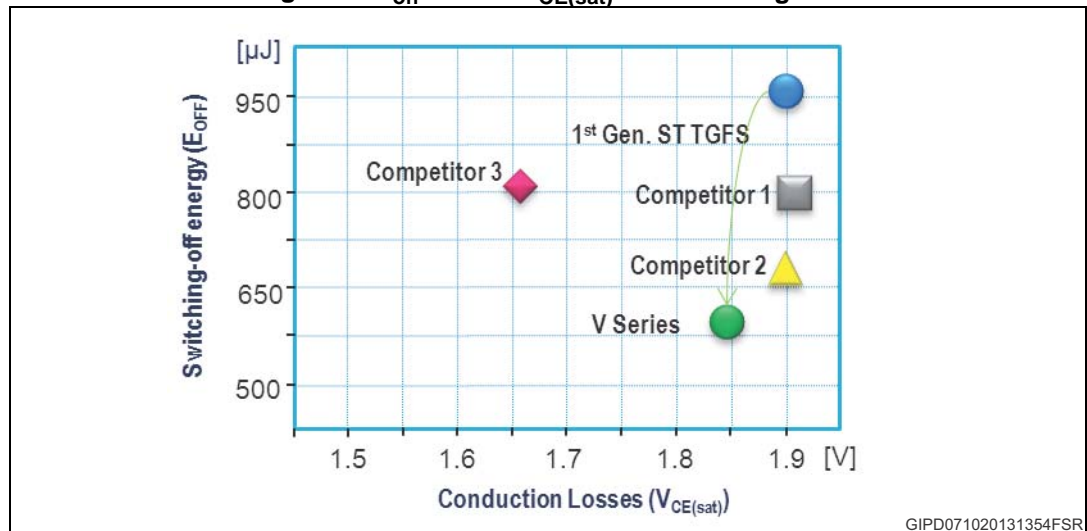
Since E_{off} and $V_{CE(SAT)}$ have been reduced comparing the new V series to the previous TGFS generation, the great technological innovation, which has let ST exceed the competitors' performance, is evident.

Measurement tests of the competitor (2) doesn't confirm its typical specification values.

The gap of V series versus the recognized market benchmark (Competitor 1) is also highlighted in Figure 6. The switching-off energy versus collector current variation is shown as result of same size device characterization carried out at 150°C in order to take into account the temperature derating.

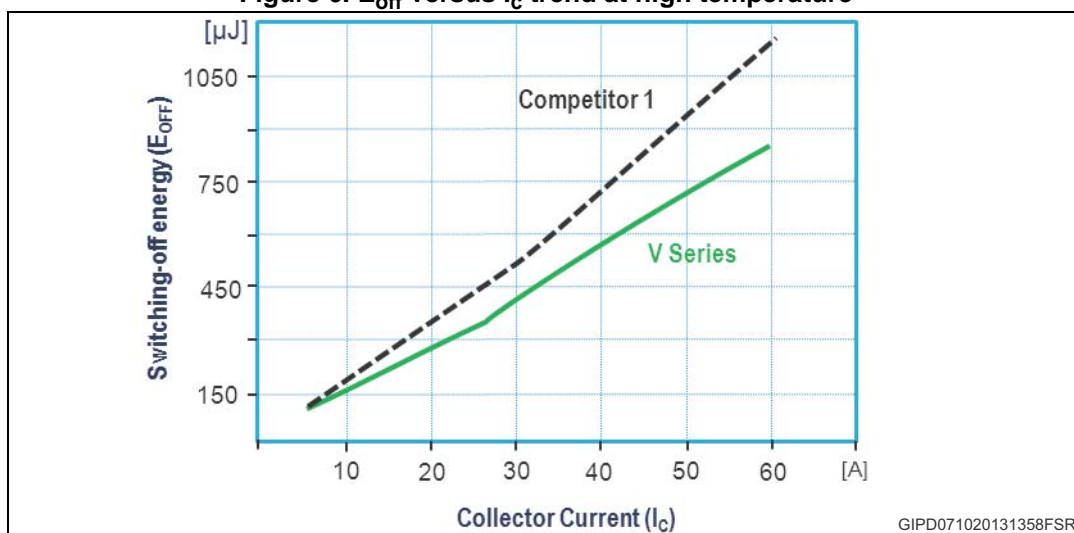
Please, note that the relevant gap is even bigger when the current, managed by the devices, is higher.

Figure 5. E_{off} versus $V_{CE(sat)}$ trade-off diagram



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Figure 6. E_{off} versus I_c trend at high temperature



4 Comparison analysis on application

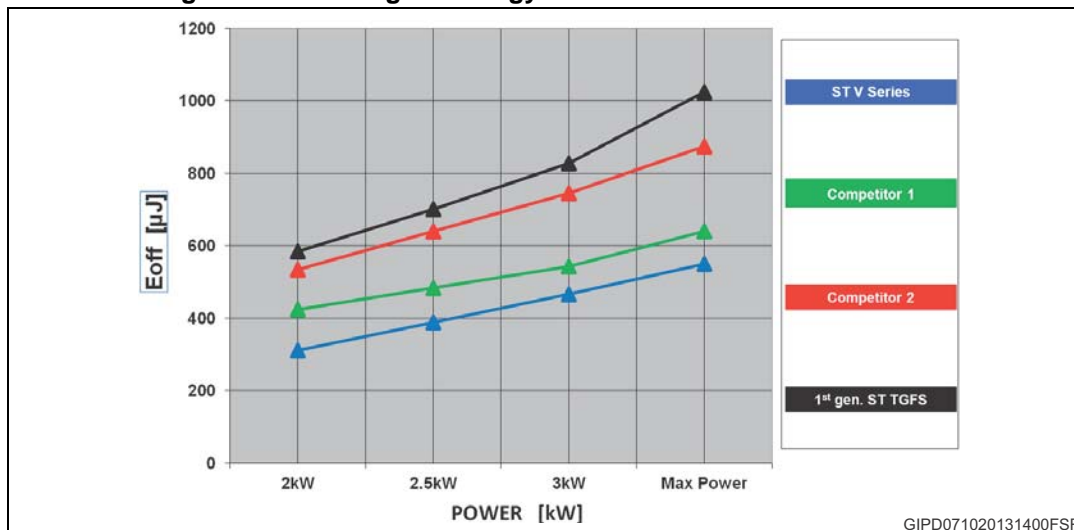
In order to get a tangible benchmark for the V series of IGBTs, two different application analyses have been carried out; they compare the previous TGFS technology, the V series and the two main same size devices proposed by the best competitors for high frequency applications.

The first application board under testing is a 4 kW welding machine whose power stage is a double switch forward converter analyzed during the full load (145 mΩ resistive load) steady-state operation, in open board conditions at room temperature and different input power levels, from 2 kW to maximum power for this machine.

With 220 V_{ac} / 50 Hz input main supply, signal waveforms and case temperature have been acquired and evaluated on two paralleled devices in the low-side part of the double switch forward converter section.

As shown in *Figure 7*, in plug-and-play conditions on the original board setting, the switching-off energy measurement clearly states that the V series technology has the lowest dynamic loss at any input power level. So, it's easy to understand how this revolutionary technology can lead to the best efficiency and thermal performance in applications whose operative frequency is fixed at 62 kHz.

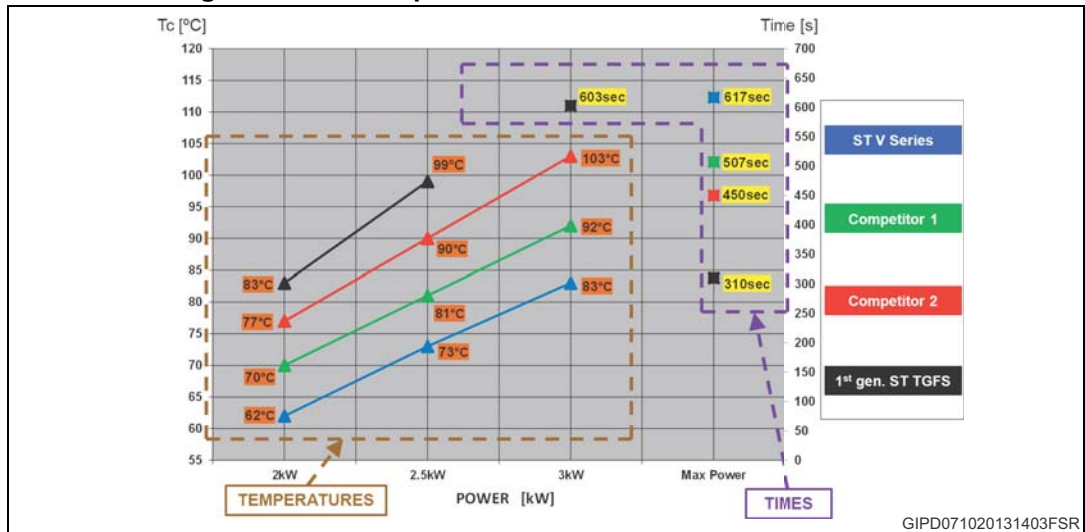
Figure 7. Switching-off energy measurement in a 4 kW welder



In fact, *Figure 8* shows case temperature trends for the hottest IGBT of the pair, and, since the V series is the coolest among all devices under testing, whatever the power level is, the best-in-class efficiency results in higher reliability too.

At the maximum input power level (almost 4 kW for this welder), the welder operation is stopped by an overtemperature self-protection after a certain period of time. Therefore, instead of measuring case temperatures, working times have been detected starting from the cold state-on condition until the maximum system temperature has been overcome (threshold set by default at around 105°C). This measurement confirms that the V series device can operate safely much longer than the devices under testing, even when the power boosts at maximum level.

Figure 8. Case temperature measurement in a 4 kW welder



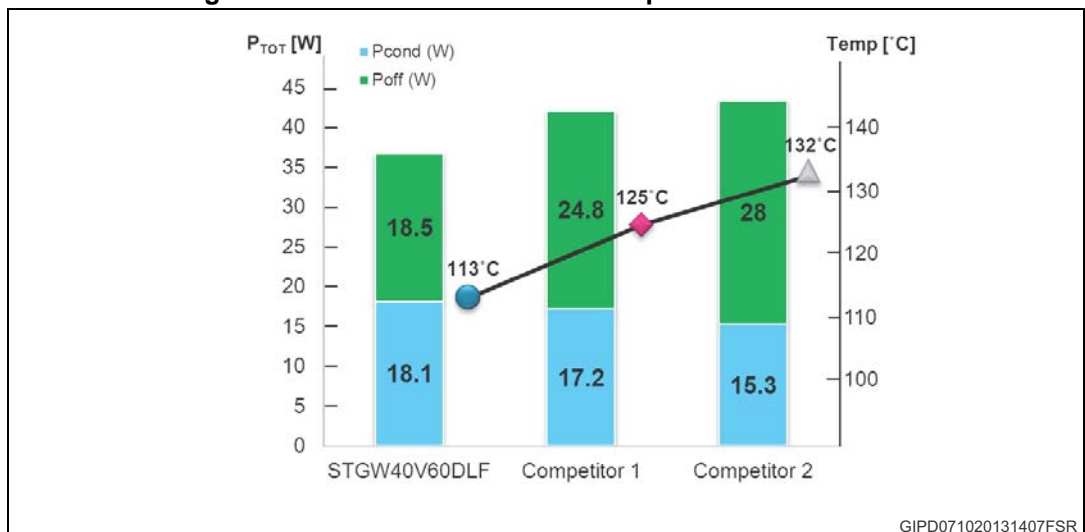
The second application analysis, proving the V series benefits, has been performed on an induction heating system whose inverter stage utilizes a half-bridge topology.

A generic induction heating pot has been used for this analysis according to the following test conditions:

- ambient temperature = 25 °C
- switching frequency = 50 kHz
- maximum off current = 55 A
- snubber capacitor = 10 nF
- resonant capacitor = 680 nF
- resonant inductor < 100 μH

After measuring the overall loss and case temperature by a thermal camera on the hottest IGBT (high-side in the half-bridge), the results in very stressful conditions (high frequency, high off current and low snubber capacitance as above-indicated) are shown in [Figure 9](#).

Figure 9. Power losses and case temperature results in IH



Thanks to the excellent switching-off energies versus $V_{CE(sat)}$ trade-off, the best performance of the V series device versus the main competitors in this market leads once again to the lowest case temperature (12 °C and 19 °C lower than competitor 1 and competitor 2, respectively).

This gap in steady-state temperature, measured on the case of the IGBTs under testing, is also emphasized by the lowest static contribution of the voltage drop on our tailored freewheeling diode to the overall loss.

Furthermore, competitor 2's device is also oversized comparing it to both ours and competitor 1's.

Finally, these analyses prove that the V series is able to get outright efficiency improvements on existing designs by a simple pin-to-pin replacement, without any design effort.

5 Product line

As summarized on the below table, a wide offer of current capability can fit any power request, avoiding oversized devices for an optimized power stage cost.

Table 1. Product portfolio

| Part number | I_c @100 °C | Anti-parallel diode type | Package options | Main applications |
|---------------|---------------|--------------------------|---|-----------------------------|
| STGx20V60(D)F | 20A | Ultra-fast | TO-220, TO-220FP D ² PAK, TO-247 TO-3P, TO-3PF | Welding PFC UPS |
| STGx30V60(D)F | 30A | Ultra-fast | TO-220, TO-220FP D ² PAK, TO-247 TO-3P, TO-3PF | Welding PFC PV UPS |
| STGx40V60(D)F | 40A | Ultra-fast | TO-220, D ² PAK, TO-247 TO-3P, TO-3PF | Welding PFC PV UPS |
| STGx40V60DLF | 40A | Low-drop | TO-247 TO-3P | IH, soft switching |
| STGx60V60(D)F | 60A | Ultra-fast | TO-247 TO-3P | Welding PFC PV UPS |
| STGx60V60DLF | 60A | Low-drop | TO-247 TO-3P | IH, soft switching |
| STGx80V60DF | 80A | Ultra-fast | TO-247 TO-3P | Welding PFC PV UPS |

Many package options are also available, and tailored anti-parallel diodes match both hard and soft switching applications. For applications that don't need freewheeling, the sole IGBT version without any co-packed diode provides a cheaper solution.

Thanks to the slight positive temperature coefficient of $V_{CE(sat)}$, the paralleling of the devices is safe allowing higher power levels to be reached.

Is it worth trying V series devices in your high frequency converter?

Find more information on st.com/IGBT

6 Revision history

Table 2. Document revision history

| Date | Revision | Changes |
|-------------|----------|------------------|
| 23-Oct-2013 | 1 | Initial release. |

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