CoolSiC™ 750 V G2 Industrial MOSFET

The latest generation of silicon carbide (SiC) MOSFET

About this document

Scope and purpose

This application note introduces the second generation (G2) of trench-based CoolSiC™ 750 V MOSFET and describes its merits when compared to the earlier generation of CoolSiC™ 750 V MOSFETs from Infineon. This application note includes technology parameters, figure of merits, target applications, and topologies and describes the latest and most important additional benefits for designers.

The purpose of this document is to explain the features of this new family of products. Important application topics are covered to help in designing systems with maximum performance and reliability.

Intended audience

This application note is intended for design engineers, technicians, and developers of electronic systems.

Table of contents

1 Introduction

CoolSiC™ 750 V G2 MOSFETs are developed to meet the increasing demand of modern industrial power electronics applications (refer to Section 1.2 for target applications). CoolSiC™ 750 V G2 MOSFETs are completely compatible with any system incorporating the predecessor technology (CoolSiC™ 750 V G1).

Key features of CoolSiC™ 750 V G2 MOSFETs are:

- **Faster switching speeds:** CoolSiC™ 750 V G2 MOSFETs can switch faster than previous generation leading to lower switching losses thus enabling switching at higher frequencies and, in turn, smaller and lighter passive components (e.g., inductors and capacitors) in power converters
- **Reduced parasitic capacitance (C_{oss}, C_{iss}, C_{rss}):** Lower parasitic capacitances minimize switching losses, particularly at high voltages and frequencies
- **Reduced gate charge (Q_g):** Lower gate charge allows for faster switching and reduces gate driving losses, making them more efficient under high-frequency operation
- **Improved body diode performance:** The intrinsic body diode in CoolSiC™ 750 V G2 MOSFETs has better forward recovery characteristics compared to CoolSiC™ 750 V G1 MOSFETs, reducing forward recovery losses in bridge configurations
- **Extended negative gate driving voltage:** CoolSiC™ 750 V G2 MOSFETs allows for extended gate driving capabilities, enabling design engineers with greater design margins and enables multi source compatibility with other vendors
- **Enhanced thermal performance:** CoolSiC™ 750 V G2 MOSFETs in Q-DPAK package can operate at higher junction temperatures (up to 200°C allowable for a total cumulative 100 hours in lifetime, and up to 7500 temperature cycles, where the maximum ΔT is limited up to 100°C), improving thermal management and reliability and ideal for surge events in the applications

These characteristics make CoolSiC™ 750 V G2 MOSFETs ideal for use in various applications where efficiency and performance are critical. One of the key benefits is reduced energy loss during power conversion processes, which enhances overall efficiency and improves performance. Additionally, the higher switching frequency operation, enabled by this new generation of 750 V SiC MOSFETs, allows for smaller and lighter passive components, contributing to the high power density of the system. Furthermore, their robustness and reliability under harsh conditions ensure better long-term performance and lower maintenance costs. The integration of SiC MOSFETs thus supports the requirements of high efficiency, high power density, and highly reliable power conversion systems used in multiple industrial applications.

The increasing demand for infrastructural upgrades with higher power and higher power density in many applications necessitates the adoption of highly efficient power semiconductor devices. Infineon's latest generation CoolSiC™ 750 V G2 MOSFETs addresses key application requirements, offer superior efficiency, robustness and enhanced performance. Its ability to operate at higher switching frequencies with optimum losses not only supports the achievement of higher power densities but also facilitates more compact and lightweight designs.

1.1 Portfolio

Table 1 CoolSiC™ 750 V G2 MOSFETs portfolio

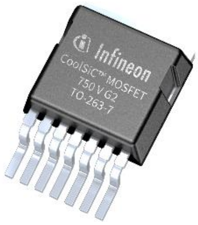
$R_{DS\,(on)}$, typ., 25°C [mΩ]	Q-DPAK	D^2 PAK-7	TO-247-4
			
60	IMDQ75R060M2H	IMBG75R060M2H	IMZA75R060M2H
50	IMDQ75R050M2H	IMBG75R050M2H	IMZA75R050M2H
40	IMDQ75R040M2H	IMBG75R040M2H	IMZA75R040M2H
33	IMDQ75R033M2H	IMBG75R033M2H	IMZA75R033M2H
25	IMDQ75R025M2H	IMBG75R025M2H	IMZA75R025M2H
20	IMDQ75R020M2H	IMBG75R020M2H	IMZA75R020M2H
16	IMDQ75R016M2H	IMBG75R016M2H	IMZA75R016M2H
11	IMDQ75R011M2H	IMBG75R011M2H	IMZA75R011M2H
7	IMDQ75R007M2H	IMBG75R007M2H	IMZA75R007M2H
4	IMDQ75R004M2H	–	–

Table 1 shows a part of the broader 750 V G2 product roadmap. These products with typical $R_{DS(on)}$ ranging from 4 mΩ to 60 mΩ are included but not limited in the packages shown in the table.

1.2 Target applications

Some key industrial applications in which 750 V G2 Silicon Carbide (SiC) MOSFETs is a good fit are:

- Solid-state circuit breaker
- Datacenter and AI server SMPS
- EV charging and energy storage
- Solar PV inverters and UPS

The best-in-class low ohmic CoolSiC™ 750 V G2 MOSFETs such as the IMDQ75R004M2H (4 mΩ) and IMDQ75R007M2H (7 mΩ) provide designers with highly efficient and reliable solutions in applications, such as solid-state relay and circuit breaker, requiring operation with overlapping high voltage and high current for short duration, yet offering exceptional thermal performance through the benefits of top-side-cooling and reduced power losses. By leveraging the ultra-low on-resistance and superior thermal management capabilities, these devices enable more compact, energy-efficient, and thermally optimized designs. This enables these devices to enhance system performance and reliability in both static and dynamic high-power applications.

1.3 Best-fit topologies

This new-generation technology in CoolSiC™ 750 V MOSFETs provides ideal solution in various industrial applications, and the following sections discuss some of the best-fit topologies in which designers could benefit with these devices.

1.3.1 Totem-pole PFC

Figure 1 shows totem-pole power factor correction (PFC) topology with CoolSiC™ 750 V G2 MOSFETs (Q1 and Q2) in the fast leg and CoolMOS™ MOSFETs (Q3 and Q4) in the slow leg. For high input AC line voltage systems, the CoolSiC™ 750 V G2 is a good-fit in both fast leg and slow leg of totem-pole PFC, offering a one-size-fits-all solution in the AC-to-DC power stage. At high switching frequency in the fast leg, the CoolSiC™ 750 V G2 MOSFETs offer the right solution to achieve higher efficiency and power density in this topology.

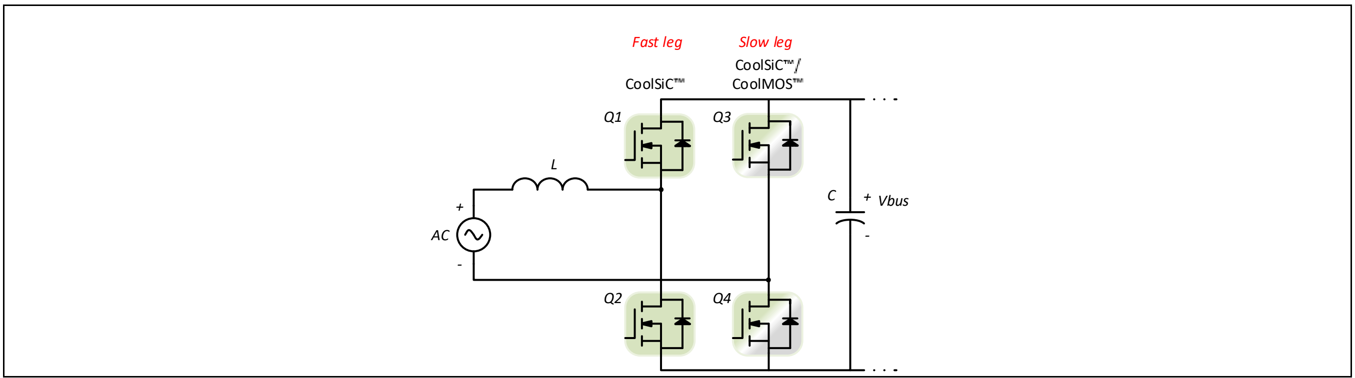


Figure 1 Totem-pole PFC rectifier power stage

Figure 2 shows the operational modes of the totem pole during the positive and negative halves of the AC-line cycle. CoolSiC™ MOSFETs (fast leg) operate at high switching frequency with the function of the boost switch and rectifier switch, while the CoolMOS™ MOSFETs (slow leg) operate at line frequency with the function of line rectifier.

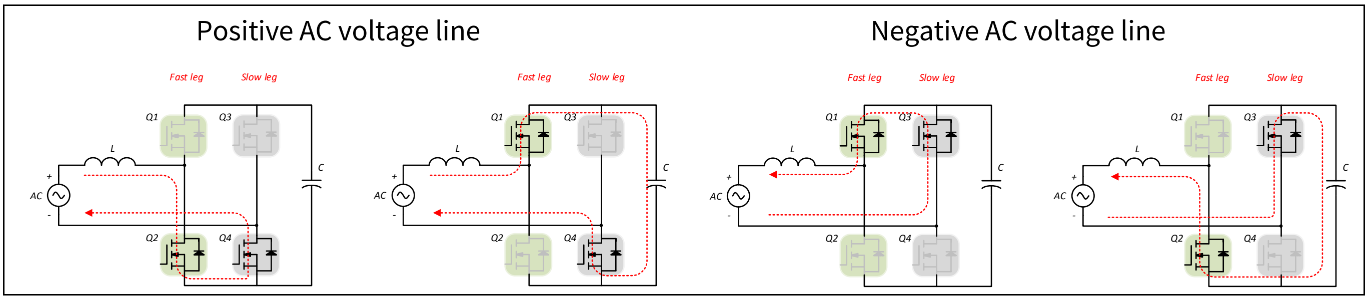


Figure 2 Operation principle during magnetizing and demagnetizing phases

In the positive AC line cycle operation, Q4 is continuously conducting. During the magnetizing phase, the Q2 turns on and the converter operates like a standard PFC, magnetizing the PFC choke. After Q2 turns off, the body diode of Q1 conducts. Finally, Q1 actively turns on and the demagnetizing phase begins. During this phase, Q1 acts as a synchronous boost switch. When synchronous boost turns off, there is a short period in which the body diode of Q1 conducts again and Q2 actively turns on, leading to a hard commutation on the conducting body diode. This hard commutation is present in every switching cycle on one of the two CoolSiC™ MOSFETs.

The negative AC line cycle operation is the same as the positive AC line cycle, except in this case, Q3 is continuously conducting. During the magnetizing phase, the Q1 turns on and the converter operates like a standard PFC, magnetizing the PFC choke. After Q1 turns off, the body diode of Q2 conducts. Finally, Q2 actively turns on and the demagnetizing phase begins. During this phase, Q2 acts as a synchronous boost switch.

As seen in this topology, lowest possible Q_{fr} is desired during every switching cycle to improve efficiency, as there is hard communication on the conducting body diode. Hence, CoolSiC™ 750 V G2 MOSFET, with related benefits discussed in subsequent sections, is the right fit for applications using this hard switching topology for achieving high efficiency due to its outstanding technology parameters.

1.3.2 LLC converter

CoolSiC™ MOSFETs enables higher efficiency and the possibility to increase the switching frequency in an LLC converter due to the ease of achieving full zero-voltage switching (ZVS). Figure 3 shows the full-bridge LLC topology with CoolSiC™ 750 V G2 MOSFETs on the primary side. Its many benefits such as high efficiency, wide input voltage range, low EMI, and high-power density make it a preferred choice for many industrial applications, for example, datacenter and AI server power SMPS.

Additionally, in conjunction with the right design selection of magnetics and resonant passive components, CoolSiC™ 750 V G2 MOSFETs offer designers the flexibility to enable LLC operation with a wider range of voltages such as architectures requiring higher bus voltage and/or higher output voltages. Depending on the system architecture and application requirements, the LLC output voltage can be a low voltage, e.g., 12 V–50 V or high voltage, e.g., 400 V or above. By leveraging the advantages of LLC converters, designers can create compact, efficient, and cost-effective power solutions for the future.

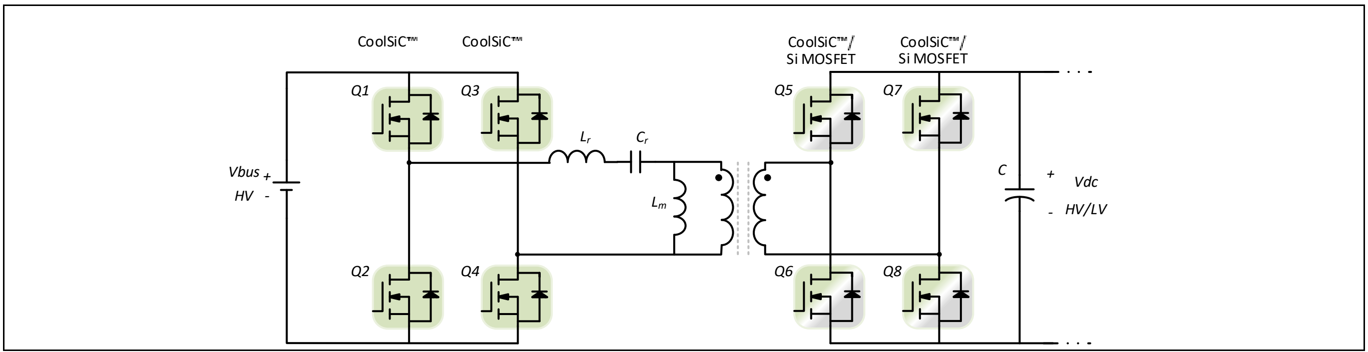


Figure 3 **Structure for LLC converter power stage**

1.3.3 Bidirectional DC-to-DC CLLLC converter

Figure 4 shows a DC-to-DC converter configured as a CLLLC converter in bidirectional operation for energy storage applications. To meet the wide input and output voltage requirements in energy storage, CLLLC converter topology is a popular candidate for designers. In a system with high bus voltage (up to 600 V DC) and high current requirements, the CoolSiC™ 750 V G2 devices are the right-fit in primary side high voltage MOSFETs, as they enable high switching frequency and achieve high efficiency power conversion.

Based on the output voltage requirements in the battery storage system, the secondary side MOSFETs are selected based on their rated blocking voltage. The mode of converter operation determines the direction of power flow, i.e., from high voltage to low voltage or vice versa.

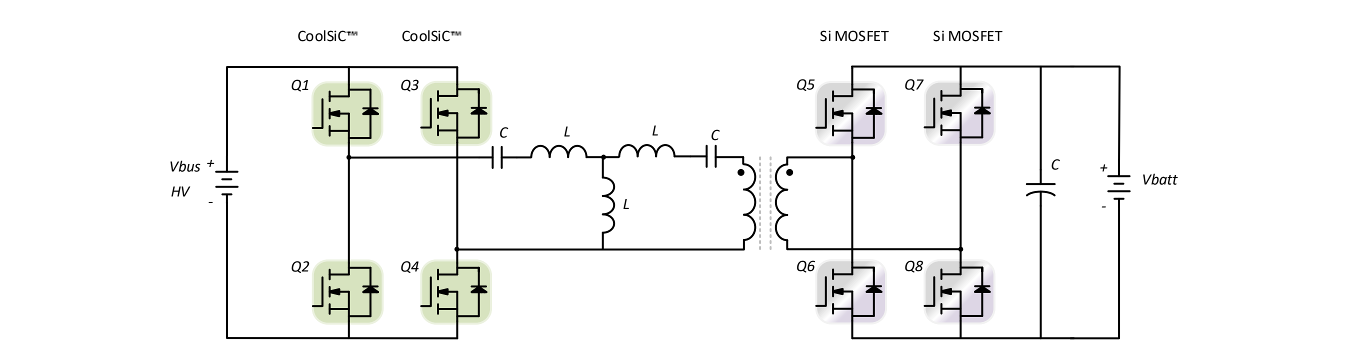


Figure 4 **Bidirectional CLLLC converter for battery storage application**

1.3.4 Solid-state circuit breaker

Due to their fast response time, robustness, and excellent performance, SiC devices are gaining popularity in solid-state circuit breaker applications. The key device requirements are:

- Continuous current conduction
- High-current handling capabilities
- High current avalanche capabilities
- Fast reaction time and high di/dt under fault conditions

To meet these requirements, CoolSiC™ 750 V G2 MOSFETs offers best in class 4 mΩ (IMDQ75R004M2H) and 7 mΩ (IMDQ75R007M2H) in top side cooling Q-DPAK that enables lower on state losses and better thermal dissipation.

The application of CoolSiC™ 750 V G2 MOSFET in solid-state circuit breaker requires two devices connected in a source connected back-to-back arrangement to achieve bidirectional current capability in the main branch, as shown in Figure 5.

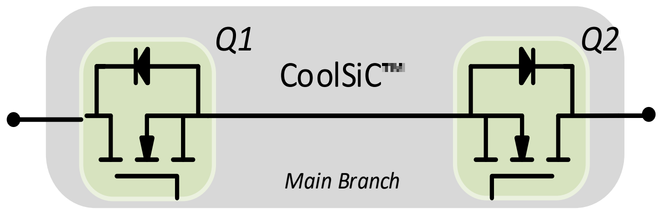


Figure 5 **CoolSiC™ 750 V G2 MOSFETs connected in back-to-back arrangement**

2 Technology parameters

This section describes the most important technology parameters and provides general recommendations for the usage of CoolSiC™ 750 V G2 MOSFETs. The comparison is represented between IMDQ75R060M2H and IMDQ75R060M1H as both products represent the same typical $R_{DS(on)}$.

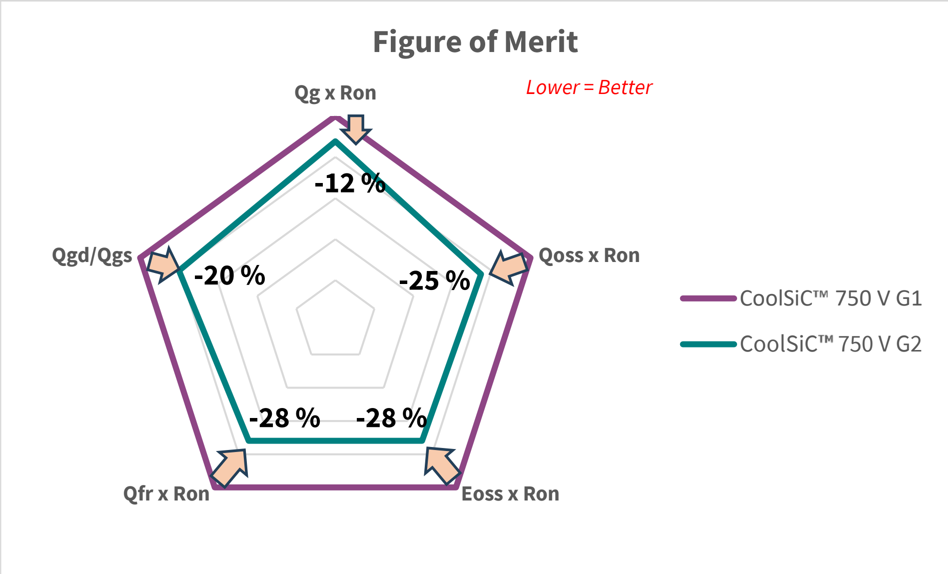


Figure 6 CoolSiC™ 750 V G2 shows the best FOMs

As shown in Figure 6, CoolSiC™ 750 V G2 shows an improved figure of merit (FOM) compared to CoolSiC™ 750 V G1. These figure of merits in applications can be translated to application-relevant benefits such as faster switching speeds, smaller system deadtime, and lower switching losses.

2.1 $R_{DS\ (on)}$ over junction temperature

The $R_{DS(on)}$ temperature coefficient of MOSFETs is a vital parameter in the design and operation of power converters. It influences the design considerations related to performance such as efficiency, thermal management, etc., and reliability aspects, such as safe operation, stability, and operational lifetime.

The $R_{DS(on)}$ shows a positive temperature coefficient which results in an increased $R_{DS(on)}$ value at higher temperatures. Therefore, designers need to consider in their calculations the $R_{DS\ (on)}$ value at higher temperatures based on the application conditions. As an example, in many industrial power electronics applications, power MOSFETs could operate well above 100°C, and within the design margins, up to the maximum rated junction temperature. Figure 7 shows the normalized $R_{DS(on)}$ dependence on junction temperature (Tj) and it can be noted that the typical $R_{DS(on)}$ at a junction temperature of 150°C is approximately 1.6 times of the typical $R_{DS(on)}$ at 25°C. The CoolSiC™ 750 V G2 show slightly smaller temperature coefficients compared to G1 at high temperatures, but at temperatures below 25°C and negative temperatures, the $R_{DS(on)}$ behavior w.r.t temperature deviates between G1 and G2 due to difference in technology.

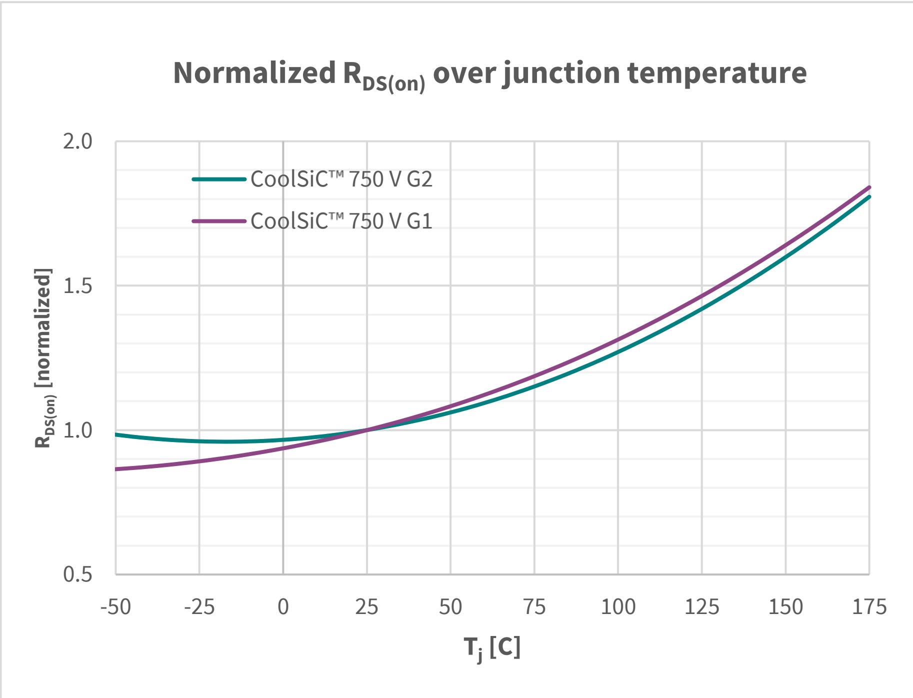


Figure 7 $R_{DS(on)}$ **temperature coefficient comparison between CoolSiC™ 750 V G2 vs. G1**

2.2 Output capacitances

Lower parasitic capacitances indicate faster switching speed and hence lower switching losses. As shown in Figure 8, a lower output capacitance in CoolSiC™ 750 V G2 compared with CoolSiC™ 750 V G1 leads to a lower Q_{oss} and E_{oss} and this enables lower switching losses.

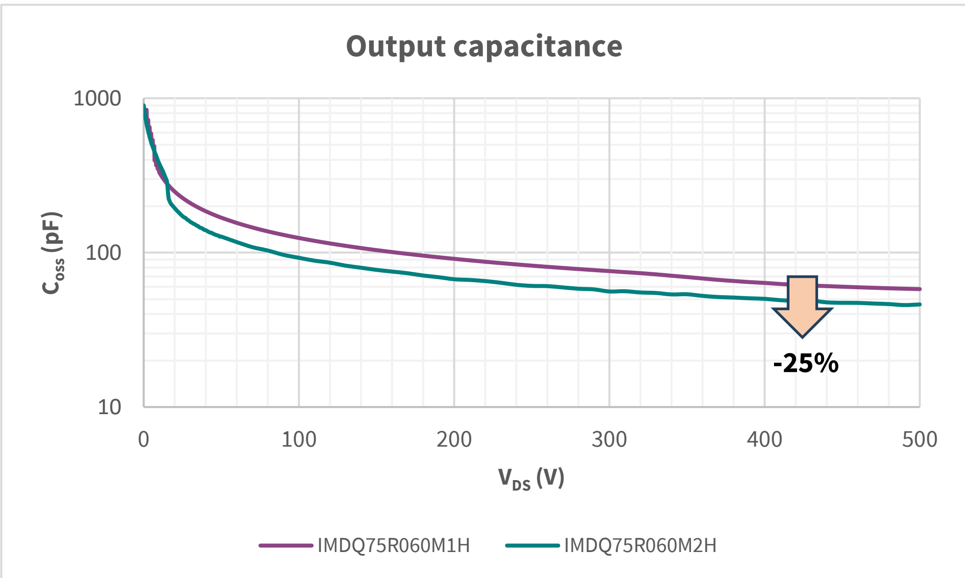


Figure 8 **Capacitances comparison CoolSiC™ 750 V G2 vs. G1**

2.3 Gate charge

The gate charge is an indicator of how fast the gate of a MOSFET can be turned on and off. Furthermore, it describes the charge needed to fully activate the device and provides an indicator for driving losses.

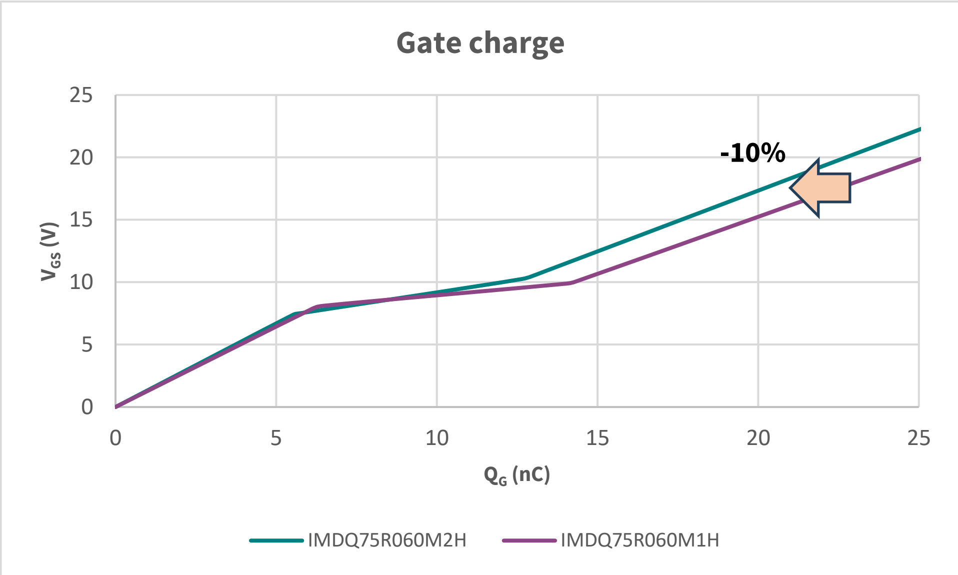


Figure 9 **Q_G comparison: CoolSiC™ 750 V G2 vs. G1**

As shown in Figure 9, the reduced gate charge in CoolSiC™ 750 V G2 compared to G1 help reduce gate drive losses, making them more efficient in high-frequency application.

2.4 Body diode reverse recovery

The forward recovery characteristic of the body diode of a MOSFET is a crucial factor in the design and performance of high power converter applications demanding high efficiency, especially in hard-switching topologies. It directly impacts efficiency, switching losses, thermal management, and overall system reliability. The following sections provide a detailed explanation of its importance in power converters:

Body diode forward recovery directly impacts:

- **Efficiency:** Lower forward recovery losses improve converter efficiency
- **Switching performance:** Fast forward recovery enables higher switching frequency operation
- **Thermal management:** Reduces overall power losses and heat dissipation

Figure 10 shows that CoolSiC™ 750 V G2 MOSFETs have much lower Q_{fr} compared to CoolSiC™ 750 V G1.

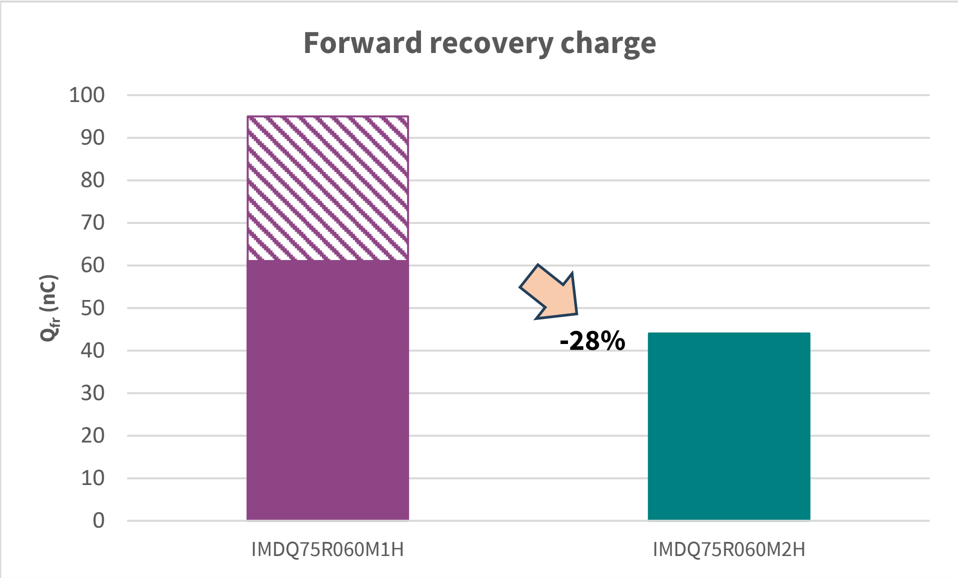


Figure 10 Q_{fr} **comparison: CoolSiC™ 750 V G2 vs. G1 MOSFETs**

It is important to note that for CoolSiC™ 750 V G2 product datasheets, a more accurate nomenclature of the body diode forward recovery is used than in CoolSiC™ 750 V G1 product datasheets. The old nomenclature of body diode forward recovery charge i.e. Q_{fr} included the parasitic charge from the test setup, i.e., PCB, probes, inductor, etc., (shaded portion in Figure 10), whereas the new nomenclature of Q_{fr} in CoolSiC™ 750 V G2 is shown not including this parasitic charge, as also explained in Figure 11.

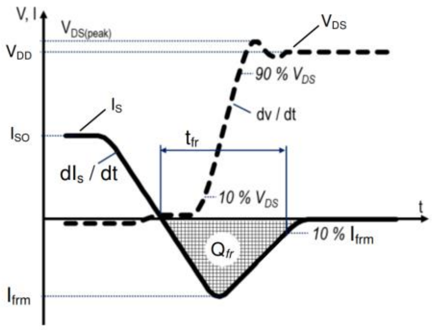


Figure 11 **Body diode forward recovery waveform**

In Figure 11, Q_{fr} includes Q_{oss} and excludes measured parasitic charge Q_{par} (PCB, probes, inductor, etc.).

3 Extended junction temperature of operation

Silicon carbide (SiC) MOSFETs offer significant advantages over traditional silicon MOSFETs, particularly in high-temperature and high-power applications. Infineon CoolSiC™ 750 V G2 MOSFET in Q-DPAK package is qualified to operate up to a maximum junction temperature of 175°C along with an extended temperature of 200°C allowable for a total cumulative 100 hours in lifetime, and up to 7500 temperature cycles, where the maximum ΔT is limited up to 100°C.

This extended range in Q-DPAK package is introduced only for use under overload conditions especially in applications like solid-state circuit breaker to offer designers additional flexibility in their system design.

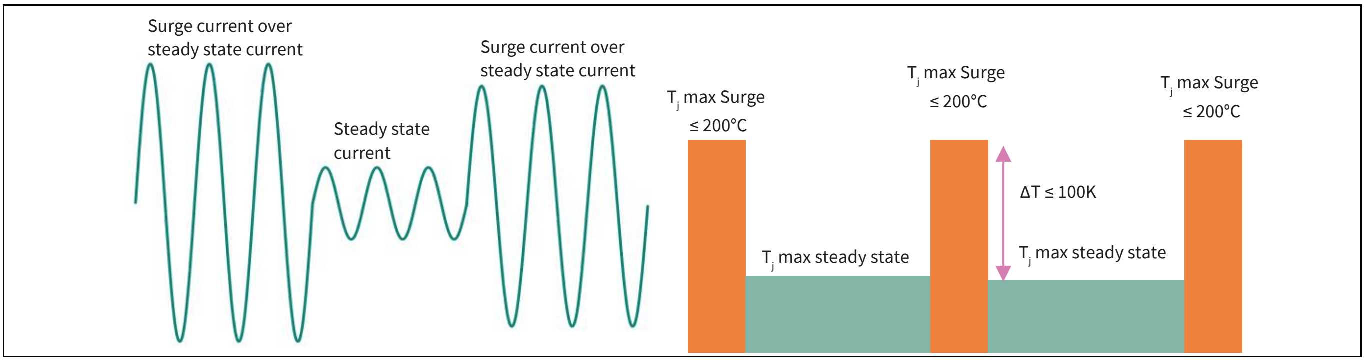


Figure 12 Example load variation during a surge event and corresponding junction temperature surge events

4 Negative gate driving voltage

CoolSiC™ 750 V G2 MOSFETs do not need negative gate drive because the Parasitic Turn-On (PTO) factor is very low and show the best behavior with respect to re-turn on behavior in the market. However, it allows for extended gate driving capabilities, supporting static gate voltages of up to -7 V and transient gate voltages of up to –11 V, a notable improvement over the previous CoolSiC™ 750 V G1 MOSFETs. This enhanced voltage tolerance provides engineers with greater design margins and enables multi source compatibility with other vendors.

Parasitic turn-on is a well-known issue in SiC MOSFETs if not driven properly in hard switching applications, primarily caused by the miller effect, high dv/dt, and parasitic inductance. Significant PTO susceptibility can lead the device to a shoot-through event, increased losses, and device failure. By implementing strategies such as negative gate-source biasing, miller clamp, optimized PCB layout, and advanced gate drivers, PTO effect can be minimized. A popular way to minimize PTO susceptibility is to negatively bias gate to source voltage during turn-off.

The parasitic turn-on (PTO) factor can be estimated according to the formula:

$$PTO\ Factor\ =\ \frac{Q_{GD}\ at\ 500V}{Q_{GS}\ at\ V_{th}}$$

Equation 1

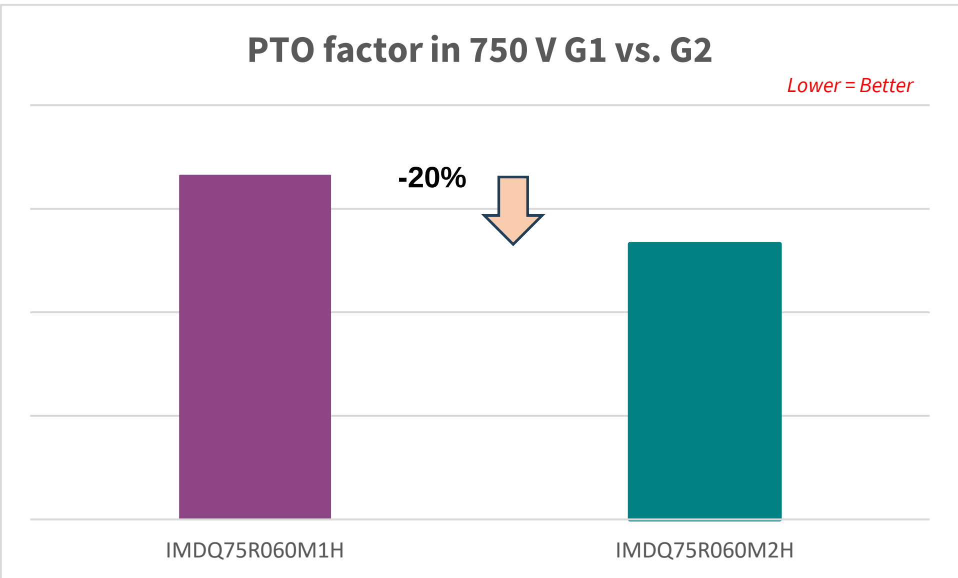


Figure 13 Parasitic turn on factor

The PTO factor, i.e., the ratio of $Q_{GD}\ at$ 500 V to $Q_{GS}\ at\ V_{gs(th)}$ in CoolSiC™ 750 V G2 is lower than CoolSiC™ 750 V G1 and hence improves further MOSFET immunity and susceptibility to spurious or parasitic turn-on due to high dv/dt in hard switching.

Additionally, with the higher $V_{gs(th)}$, CoolSiC™ 750 V G2 MOSFET benefits with further safety from parasitic turn-on event with good safety margins compared to the older generation from Infineon and other vendors in the market.

As described in the available literature on CoolSiC™ technology from Infineon, there is a possibility of a $V_{gs(th)}$ drift over the device lifetime caused by switching events with negative voltage gate turn-off in CoolSiC™ MOSFETs. Therefore, a corresponding $R_{DS(on)}$ drift is possible over the lifetime, as with all SiC MOSFETs that are available on the market.

Figure 14 shows data derived from the worst-case end-of-mission profile assessment showing the $R_{DS(on)}$ % drift on y-axis vs. the number of switching cycles on x-axis, if the devices exceed the static or transient gate-source voltage limit given in the datasheets. These diagrams enable design engineers in selecting the system parameters that affect the MOSFET operation, such as overshoots and undershoots in the gate to source voltage, within the bounds of the device datasheet ratings that serves as best-fit in the application with consideration of the parametric drift over lifetime.

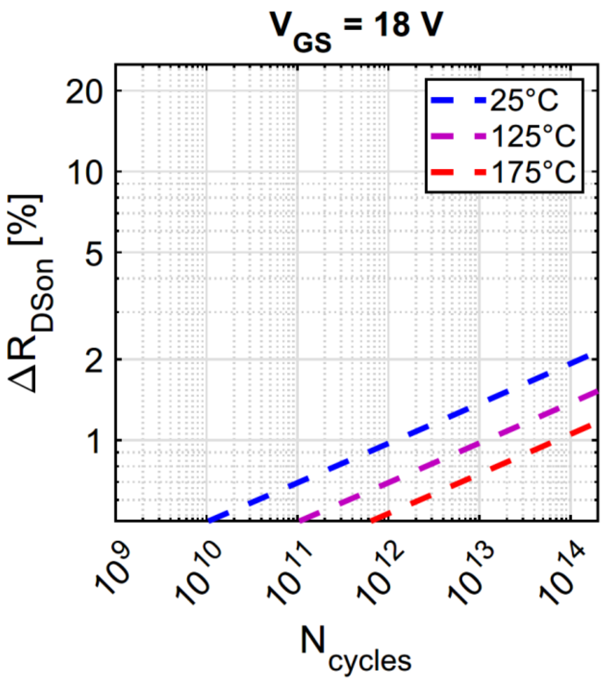


Figure 14 End of lifetime $R_{DS (on)}$ drift vs. number of switching cycles with negative turn-off gate-source voltage

5 Application tests

With CoolSiC™ 750 V G2 MOSFETs, lower switching losses are achievable compared to the previous generation due to improvements in the device's parasitic capacitance.

5.1 Switching energy measurements in half-bridge configuration

This section provides the switching measurement comparison of CoolSiC™ 750 V G2 MOSFET (IMDQ75R060M2H), CoolSiC™ 750 V MOSFET G1 (IMDQ75R060M1H), and 60 mΩ 750 V SiC MOSFET from vendor 1 all in top side cooling packages, measured at case temperatures 25°C and 150°C.

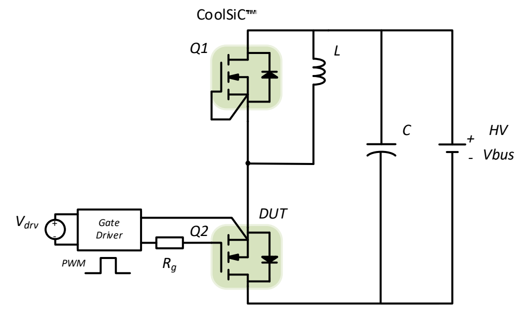


Figure 15 Test setup for switching losses measurement

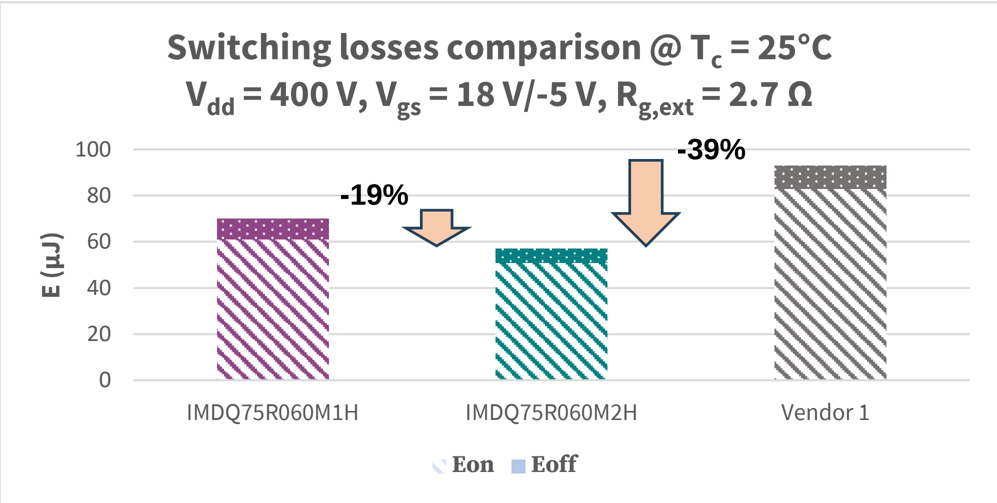


Figure 16 Switching losses comparison at 25°C between CoolSiC™ 750 V G2, G1, and vendor 1

As seen in Figure 16 and Figure 17, CoolSiC™ 750 V G2 has lowest E_{on} and E_{off} at both room and hot temperatures.

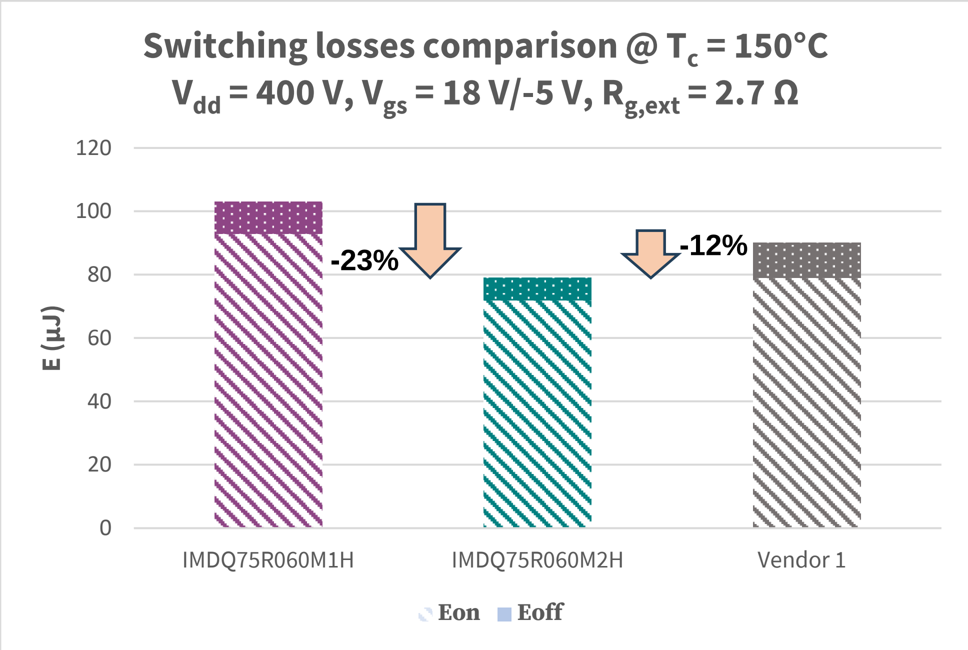


Figure 17 Switching losses comparison at 25°C between CoolSiC™ 750 V G2, G1, and vendor

5.2 3.3 kW Totem-pole PFC

In hard-switching applications, such as totem-pole PFC shown in Figure 1, there is an inverse relation between efficiency and switching frequency, since each switching transition incurs energy loss due to voltage -current overlap during switching turn-on/turn-off events.

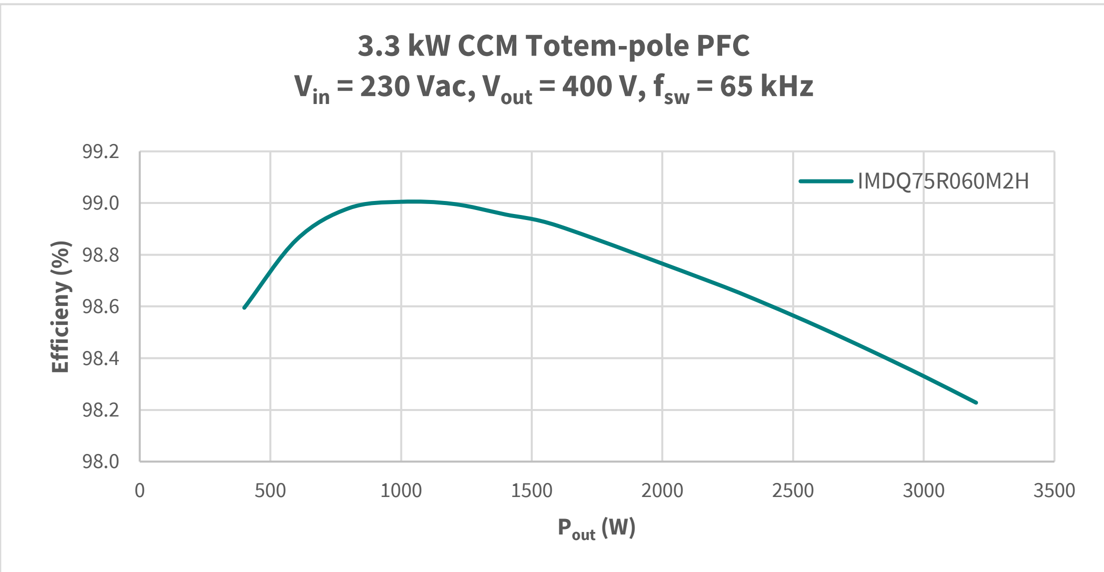


Figure 18 Efficiency results of 3.3 kW totem-pole PFC with CoolSiC™ 750 V G2

Due to the improved switching performance in CoolSiC™ 750 V G2 MOSFETs, at 65 kHz, a peak efficiency of 99% is achieved in totem-pole PFC, which can be further improved with a lower $R_{DS(on)}$ design.

5.3 3.3 kW LLC converter

In soft-switching applications, there is negligible overlap between voltage and current during switching transitions, thereby minimizing switching losses. This enables operation at much higher switching frequency and advantageous for high-efficiency applications. The 3.3 kW LLC converter used for evaluation is a half-bridge LLC variation of the topology shown in Figure 3.

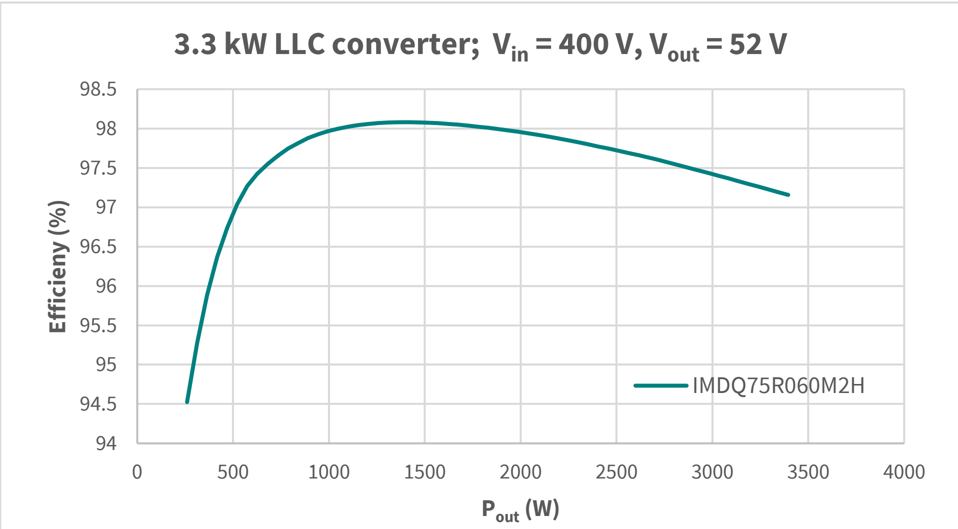


Figure 19 Efficiency results of 3.3 kW LLC converter with CoolSiC™ 750 V G2

5.4 6.6 kW bidirectional CLLLC converter

A 6.6 kW CLLLC converter as shown in Figure 4, with IMDQ75R016M2H MOSFETs in the primary (HV) side is operating at switching frequency of 200 kHz and the measurements are taken at the operating conditions of 500 V and 600 V input bus voltages, and 100 V and 120 V output battery voltages respectively, showing a typical system in energy storage applications.

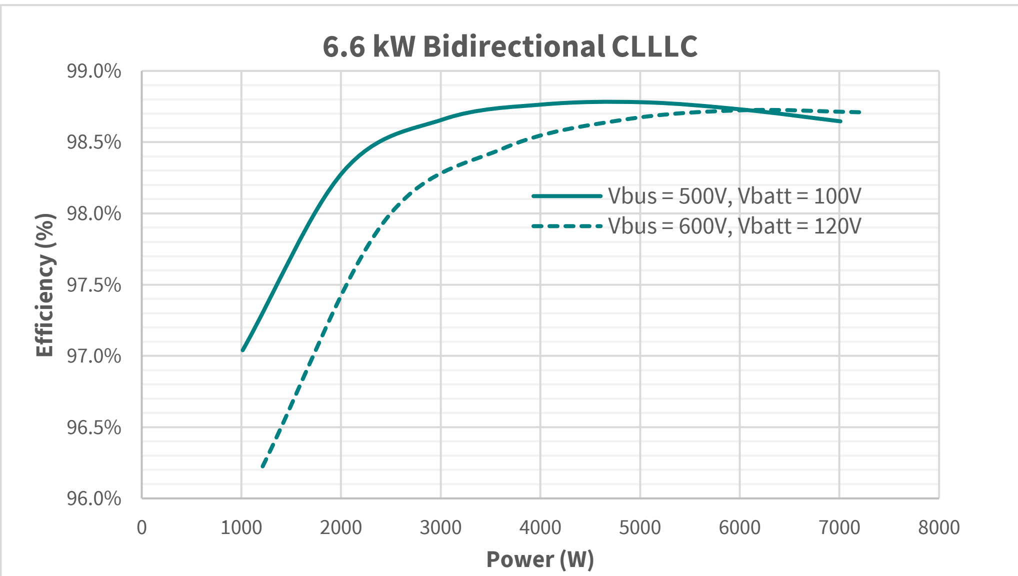


Figure 20 Efficiency results of 6.6 kW CLLLC converter with 500 V and 600 V bus voltage systems

5.5 High-current inductive clamping and linear mode measurements

In solid-state circuit breaker applications, the high current avalanche characteristics are crucial. To test CoolSiC™ 750 V G2 MOSFETs as fit for use in these applications, the high current inductive clamp circuit enables operation of the SiC MOSFET in avalanche before the energy absorbing component (such as MOV) takes over safely. The best-in-class lowest $R_{DS(on)}$ MOSFET 4 mΩ and 7 mΩ MOSFETs in the CoolSiC™ 750 V G2 portfolio available in Q-DPAK package were measured to withstand at least the maximum peak rated current, and both devices showed smooth operation, with the 4 mΩ results shown in the following figure.

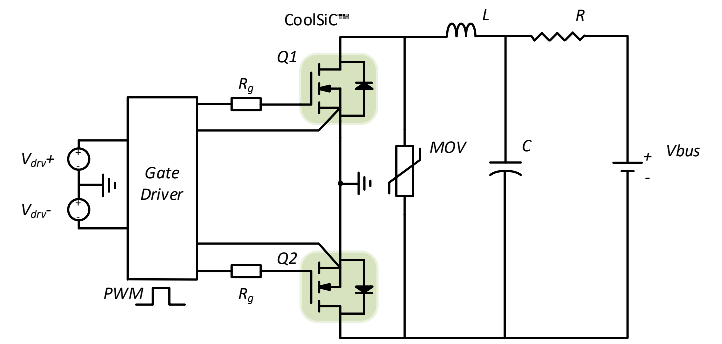


Figure 21 Test setup for high current inductive clamping measurements

For this test, the gate driving voltage and $R_{g,ext}$ used is 18 V and 10 Ω during turn-on, and 0 V and 4.7 Ω during turn-off. The current in the inductor is ramped up to the operating current selected before the CoolSiC™ 750 V G2 MOSFET is turned off going into avalanche at high current.

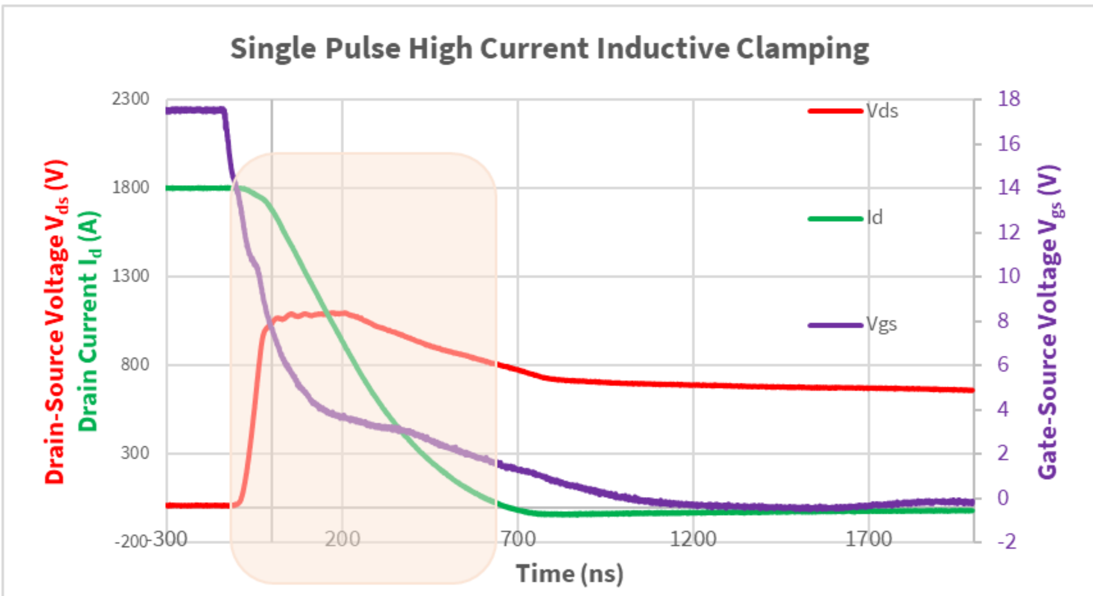


Figure 22 Results of IMDQ75R004M2H handling peak rated current under avalanche conditions

The operating current is selected based on the rated peak drain current, i.e., ~1700 A for IMDQ75R004M2H.

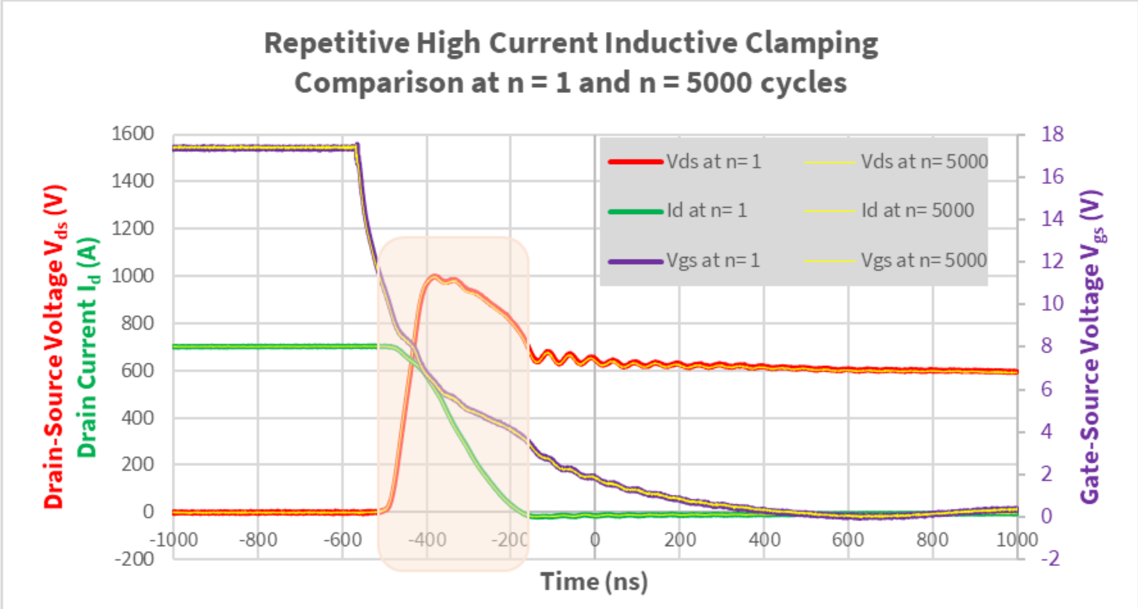


Figure 23 **Results of IMDQ75R004M2H with no deviation in waveforms after 5000 cycles**

Repetitive pulse tests are performed to study any deviation in the electrical waveforms. It is observed that even after 5000 cycles, no deviation was observed in the electrical waveforms, which is important feature for solid-state circuit breaker devices that may encounter number of high current and high voltage events in lifetime.

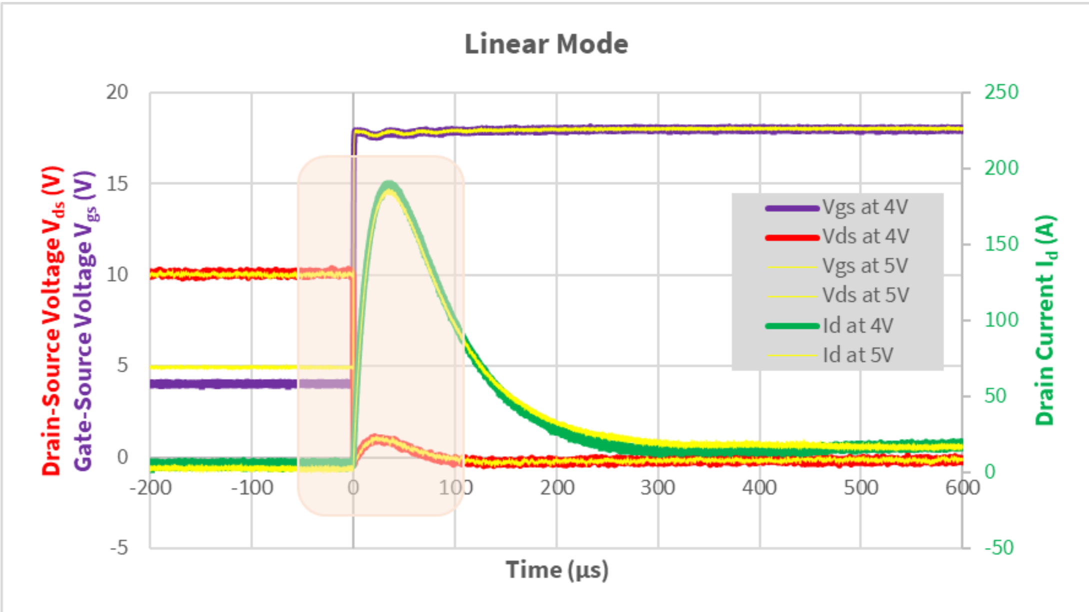


Figure 24 **IMDQ75R004M2H shows good thermal stability in linear mode operation**

Some application may require MOSFETs to operate in linear mode. From the above waveform, CoolSiC™ 750 V G2 devices are self-limiting at even low V_{gs} with no signs of thermal runaway under abnormal conditions.

References

[1] Infineon Technologies AG: *CoolSiC™ 650 V G2 MOSFET application note (AN112138)*; Available online

[2] Infineon Technologies AG: *Guidelines for CoolSiC™ MOSFET gate drive voltage window application note;* Available online

[3] How2Power.com: *Spurious Turn-On Investigation for SiC MOSFETs In hard-switched half-bridges*; Available online

[4] Infineon Technologies AG: *CoolSiC™ totem-pole PFC design guide and power loss modelling application note (AN_2212_PL52_2301_194003);* Available online

[5] Infineon Technologies AG: *3300 W CCM bi-directional totem pole with 650 V CoolSiC™ and XMC™ application note (AN_1911_PL52_1912_141352*); Available online

[6] Infineon Technologies AG: *Resonant LLC Converter: Operation and Design application note;* Available online

Revision history

Document revision	Date	Description of changes
V 1.0	2025-04-17	Initial release

Trademarks
All referenced product or service names and trademarks are the property of their respective owners.

Edition 2025-04-17

Published by

Infineon Technologies AG

81726 Munich, Germany

Do you have a question about this document?

Email: erratum@infineon.com

Document reference

AN212347