Ensure Your System Robustness by Choosing Hard Commutation Rugged Medium Voltage MOSFETs

Understanding hard commutation event and how to get the best system reliability and performance using Infineon's new 200V and 250V devices

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Today, wide range of energy-critical applications can benefit from trench MOSFETs' low Figure of Merit ($R_{DS(on)}$ x Q_g) because of the MOSFETs' high blocking voltages. Infineon's OptiMOS^{TM} power MOSFETs can, for example, achieve the breakdown voltages of up to 250V and offer industry's lowest figures of merit. However, $R_{DS(on)}$ and Q_g are not the only parameters that need to be considered while choosing proper MOSFETs for an application. An often neglected but essential example when it comes to the MOSFET selection for hard switching applications is the hard commutation of the body diode. Insufficient ruggedness of the body diode can lead to system failure and the issue becomes increasingly severe as the breakdown voltage increases. Infineon has developed a new series of hard commutation rugged devices, OptiMOS^{TM} FD 200V/250V, which reduce Q_{rr} significantly and improve system reliability and performance at the same time.

Higher voltage field-plate MOSFET fills the gap but caution required

Choosing power MOSFETs with the breakdown voltages which tightly meet the application-specific de-rating requirement allows performance optimization of the devices in terms of figures of merit — on-state drain-source resistance ($R_{DS(on)}$) and switching gate charge (Q_g). Below 200V and above 600V, the MOSFET market is well served respectively by the trench field-plate technology and the superjunction technology. To address the gap in between and to serve a wider range of energy-critical applications with increasingly stringent system efficiency requirements, trench power MOSFETs with higher blocking voltages are being developed. As the breakdown voltage is being stretched, the physical limit of silicon as a trench FET is being put to test due to the more demanding operating conditions. To consider the intrinsic body diode limits and the increasingly important hard commutation ruggedness, therefore, becomes crucial.

Body diode, reverse recovery and hard commutation

Typical symbol of a MOSFET shows that there's a body diode in every MOSFET. Which means when a MOSFET is chosen, the body diode that comes along with it is also fixed. Since the diode is physically parallel to the channel, it is important for the diode to be considered during operation especially while the channel is in the off state. More specifically, in applications where the body diode conducts, designers must make sure the body diode is behaving as desired. It is necessary to consider the breakdown voltage of the diode (normally the same as the channel), and the maximum current going through the diode, both in the forward and the reverse directions. OptiMOS^{TM} devices can normally handle continuous forward current up to the rated drain current. The reverse current occurs along with the undesired reverse recovery phenomenon. During the diode's turning off operation, reverse recovery occurs. The current goes negative and the area bounded by the negative current and the zero line denotes the reverse recovery charge (Q_{rr}). The reverse current potentially causes shoot through, and Q_{rr} yields additional loss and overshoot. This complete switching event, which involves forward-current-carrying body diode of a MOSFET experiencing reverse recovery during turn-off, is categorized as hard commutation.

In switching converters, body diodes are common instruments used to provide the freewheeling capability at no extra component cost. It is an advantage in this case where no external diode is required. However, the often neglected reverse recovery behaviour could cause device abnormality and lead to system failure. To properly select higher voltage class MOSFETs, it becomes increasingly important to consider the hard commutation event, and a reliable system requires careful selection of the MOSFETs with robust body diodes to fulfill the requirement of the application.

During the hard commutation turn-off transition, the diode is initially forward biased and it carries a positive forward current. As soon as the turn-off process is initiated, the current rolls off at a constant slope (*di/dt*) to zero, then reverses the direction. The negative current, also known as reverse recovery current (I_{rr}), finally reaches the negative peak (I_{rrm}) and then goes back up to zero. The reverse recovery process completes at this moment, and the body diode returns to its blocking state.

Reverse recovery charge (Qrr), overshoot and system robustness

The shaded area under the current curve in the negative region represents the reverse recovery charge - Q_{rr}. It is often approximated by the triangle area, where Q_{rr} can be quickly estimated by .

In a half-bridge configuration for example, reverse recovery occurs at the transition where the freewheeling body diode current of the low side pull-down FET is redirected to flow through the top side pull-up FET. The resulting reverse recovery current through the low side FET flows at the same direction as the redirected current through the top side FET. For a very short instance, the current flows directly from the input to ground; thus a shoot-through occurs. This behavior results in overshoot.

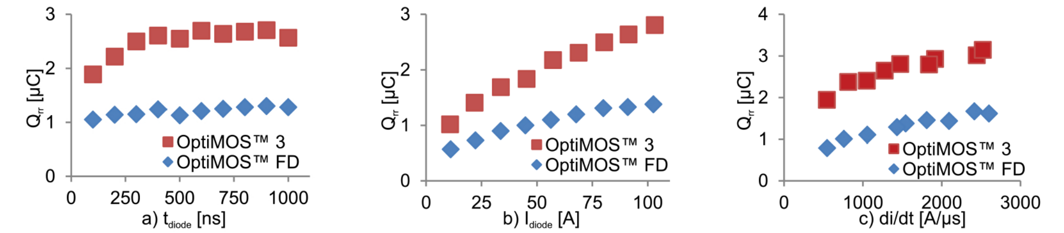

Figure 1: Qrr dependencies and OptiMOSTM FD Qrr benchmark

The amount of Q_{rr} has a direct impact on the overshoot level. The higher the Q_{rr}, the higher the overshoot. A severe overshoot puts the device into avalanche which may lead to device degradation over time. In other words, a device with higher Qrr is less susceptible to a rough hard commutation event. Therefore, Q_{rr} is a good indicator for device hard commutation ruggedness.

Qrr dependency and the key to improve system robustness

The amount of Q_{rr} depends greatly on the application condition and the device itself. Q_{rr} is influenced proportionally by the body diode conduction time, freewheeling forward current, and the commutation current slope, with different degrees of saturation.

Figure 1 shows the Q_{rr} characterization between two devices – OptiMOS^{TM} 3 and the new OptiMOS^{TM} FD 200V devices across different application conditions while keeping the other two dependents constant.

These curves suggest that by selecting hard commutation ruggedness and Q_{rr} optimized OptiMOS^{TM} FD devices, Q_{rr} reduces significantly (40% to 60%) across all application conditions. By choosing the new OptiMOS^{TM} FD devices, the designer could possibly avoid achieving the desired Q_{rr} or overshoot by tweaking the application conditions. In other words, the design efforts could potentially be minimized by omitting the following optimization or design steps:

- Tuning deadtime to reduce body diode conduction time
- Considering to a different topology in order to lower the diode conduction current
- Counterintuitively redesigning PCB to increase the commutation loop parasitic inductance or add external gate resistance in order to reduce current slope (*di/dt*)

Improve the reverse recovery behavior by selecting the new OptiMOS^{TM} FD. Q_{rr} can be reduced in the device level regardless of the application condition.

Hard commutation optimization and the benefits

From Figure 1, Q_{rr} is reduced when choosing the new OptiMOS^{TM} FD devices. Figure 2 shows the exact improvement in reverse recovery behavior. In these two hard commutation events (one with OptiMOS^{TM} 3 200V and the other with OptiMOS^{TM} FD 200V), the body diode conduction time and forward current are the same. In the diagram, it can be observed that the current rolls off at the same slope (*di/dt*) down to zero. Then it reverses the direction while in the negative region. With OptiMOS^{TM} FD, the current reaches a lower negative peak, and the recovery takes shorter time to complete. In this case, the peak reverse recovery current reduction of 20% is observed, and the Q_{rr} drops approximately 40%. The shaded area represents the Q_{rr} reduction.

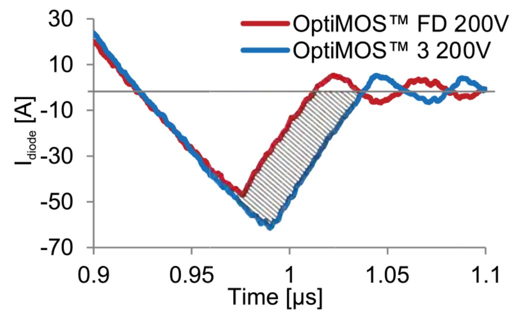

Figure 2: Commutation waveform comparison between OptiMOS3 and OptiMOSTM FD devices

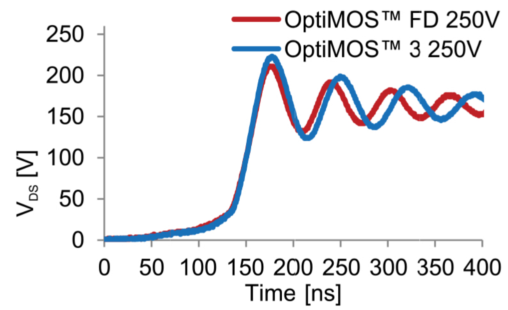

Figure 3: Overshoot comparison between 250V OptiMOSTM 3 and OptiMOSTM FD

The peak reverse recovery current is especially important for switching events where the device enters avalanche. The peak basically acts as the avalanche current which has a quadratic relationship to the avalanche energy. A reduction of 20% in avalanche current means a 36% of reduction in the energy. This significantly lowers the stress to the device and leads to an increased system reliability.

Q_{rr} reduction as explained earlier reduces overshoot. Figure 3 confirms that the new OptiMOS^{TM} device yields lower overshoot with its reduced Q_{rr} (results for 250V devices are shown as an example). This eases design efforts to meet EMI compliance and de-rating requirement often set by the end customer.

The reduction in Q_{rr} not only minimizes overshoot but also reflects performance improvement in terms of system efficiency. Q_{rr} is wasted energy, so it translates directly into power loss. 40% lower Q_{rr} means to a significant reduction in power loss caused by Q_{rr}. In the synchronous rectifier stage on Infineon's 2kW ZVS full bridge phase-shifted (ZVS FBPS) DC-DC converter demo board [2], the new OptiMOS™ devices perform better than the previous generation OptiMOS^{TM} 3 devices.

The originally optimized synchronous rectifier (SR) switches (OptiMOS™ 3 200V Best-in-Class devices) were replaced by the new OptiMOS™ FD 200V devices. 4 SR devices in total (2 in each SR branch) were replaced. The efficiency curves comparisons are shown in Figure 4.

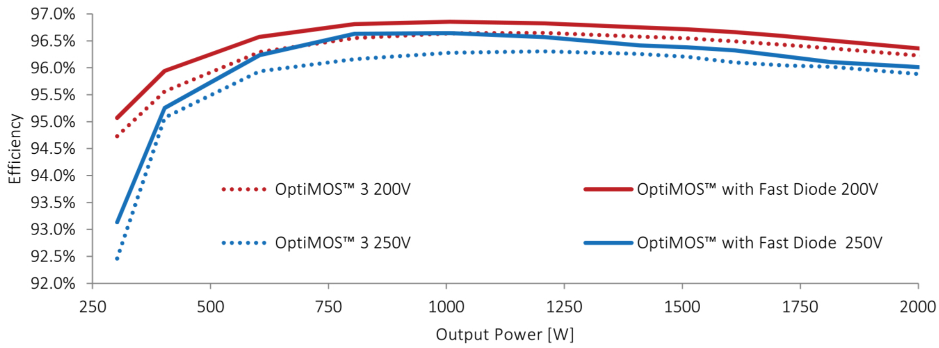

Figure 4: Efficiency comparison between OptiMOS™ FD and OptiMOS™ 3

The comparison demonstrates that by simply swapping the SR devices from previous generation OptiMOS™ 3 devices to the newest generation OptiMOS™ FD devices, significant overall efficiency boosts of up to 0.35% and 0.5%, respectively for 200V and 250V devices, were achieved.

Application-based selection

To determine whether hard commutation ruggedness optimized devices, namely OptiMOS^{TM} FD devices, are necessary for the application, it is intuitively to consider whether the hard commutation event of the body diode occurs in the application. Applications which have been identified that can benefit greatly from the new OptiMOS^{TM} FD devices include, but not limited to, secondary SR for telecom rectifier, industrial power supplies, motor drives (for 48V-110V system), DC-AC inverter, Class D audio amplifier, etc.

Conclusion

Selecting proper medium voltage MOSFETs is not only important to achieve the highest efficiency and performance but also essential to ensure system reliability. Infineon's new OptiMOS^{TM} FD 200V/250V devices optimized for hard commutation ruggedness adds an extra layer of assurance to the system. With their uncompromised best-in-class figure of merits, $R_{DS(on)}$ x Q_g, they significantly reduce device level Q_{rr}, minimize overshoot and boost efficiency when compared with the previous industry benchmark OptiMOS^{TM} 3 devices. These products provide Q_{rr} optimized solution for power system designers striving for highest standards of efficiency and reliability. Choose the new OptiMOS^{TM} devices to enjoy fastest reverse recovery, lowest reverse recovery charge, minimized overshoot, improved hard commutation ruggedness and highest efficiency.

References

[1] Application Note Hard Diode Commutation of Power MOSFET - OptiMOS™ FD 200V/250V, March 2014

[2] Application Note Evaluation Board ZVS Phase Shift Full Bridge – CoolMOS™ CFD2 and OptiMOS™ 200V, March 2013