CHALLENGES

TM4 presents an innovative control process for electronic switches in commutation cell configuration. This technique permits optimisation of overvoltage across the electronic switch, reducing the reverse recovery current in the opposite diode while at the same time accelerating the switching process. Two challenges can be added to the ones in the introduction: Slowing down the commutation to limit the overvoltage slows down the whole switching process and increases junction temperature. This method, called Reflex Dual Gate Driver Technology, further pushes the level of control of the switching process by controlling the dV/dt as well as the dI/dt.

LIMITING OVERVOLTAGE

In a single device, the IGBT combines the simple input stage of low-power capacitive Mosfets with the output stage of high-current and low-saturation-voltage bipolar transistors connected in a thyristor configuration. All these different sub-components are non-linear and commutate at different speeds.

The inherent non-linearity of the various components in the IGBT complicates its control, therefore making it difficult to operate at maximal efficiency. While it is desired to rapidly switch the IGBT on and off in order to reduce losses as much as possible, it is also required to avoid excessive collector-to-emitter overvoltage and excessive freewheeling diode recovery current.

A typical gate driver circuit is made from a voltage source that powers a current source (typically built with gate resistors). It charges the input capacitor of the IGBT called Cies at the level of the voltage source. **FIGURE 1** shows a typical gate driver powering an IGBT with its parasitic components.

The polarities shown across emitter inductance reflect the voltage obtained upon dI/dt at turn off, when Iigbt diminishes. Upon turn-on of the IGBT, the voltage across the emitter inductance is in the opposite direction.

The idea behind Reflex Gate Driver Technology is to inject a fraction of the total stray inductance voltage (which is the overvoltage across the IGBT) in the gate driver as feedback of the overvoltage across the IGBT. The voltage across

Optimisation of IGBTs During the Commutation Process

For some electronic switches, like IGBTs, optimising the control of the switching process is very difficult because of their deep non-linearity. Moreover, during the commutation process, semiconductor switch performance is mainly driven by overvoltage and junction temperature. Overvoltage depends on the speed of the current changes in the high frequency loops (HFL) and the value of the parasitic inductance of the HFL. Eliminating the connections and the isolations which create inductances and capacitors is not possible. The layout imposes a limit above which the speed of the power electronic switch must not exceed. TM4 introduces a solution.

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the emitter inductance of the IGBT is the sample of the overvoltage used with Reflex. The gate voltage is automatically adjusted to clamp the dI/dt at a fixed value.

Thanks to this, it becomes possible to slow down the gate voltage variation to just below the speed of the slowest sub-component of the IGBT during commutations. It allows the gate driver circuit to compensate for the deep non-linearity of the IGBT. That is what Reflex Gate Driver Technology does: it keeps the gate-emitter voltage in the linear region during the commutation of the current. **FIGURE 2** shows the closed loop control of the dI/dt that creates the overvoltage.

By limiting the overvoltage with high precision, Reflex Gate Driver Technology gives the system integrator the flexibility

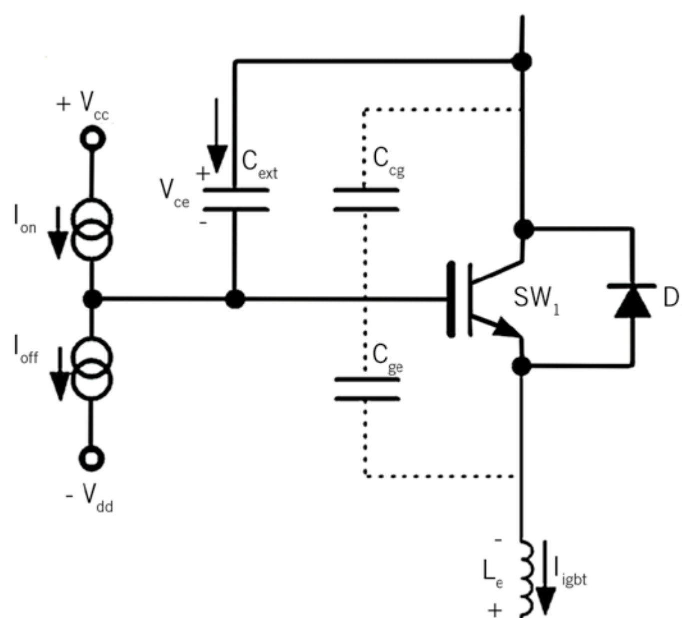

FIGURE 1 Typical gate driver powering an IGBT with its parasitic components

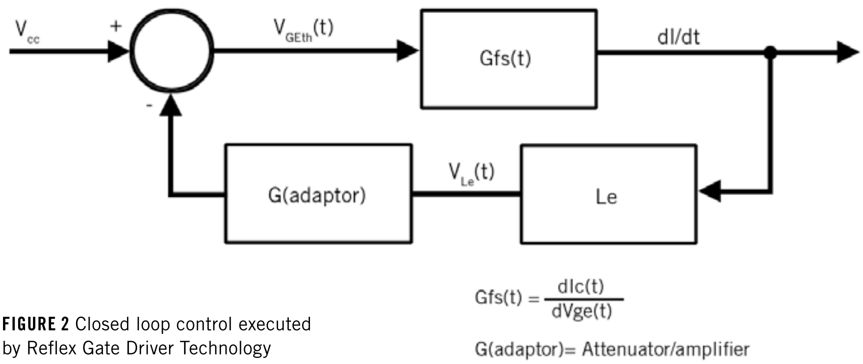

FIGURE 2 Closed loop control executed by Reflex Gate Driver Technology

to choose an optimised operating voltage according to the other sub-components of the system. For example, the torque constant of a PMM may be optimised to lower the current at the output of the drive.

LIMITING THE RECOVERY CURRENT

This section presents the advantage of controlling the dI/dt when turning ON the IGBT. The turn-on process starts with the current in the IGBT increasing up to the load current and then starting to circulate in the reverse direction in the diode. The reverse current in the diode serves to recover the charges accumulated on the P-N junction. The duration of the reverse current decreases with higher dI/dt but the amplitude of the maximum reverse current (Irrm) increases. By limiting the dI/dt during the recovery of the charges, Reflex Gate Driver controls the dV/dt across the opposite diode, which is dependent on Irrm.

Because of the non-linearity of the IGBT, the current begins to increase slowly when it is turned ON and the dI/dt increases until the diode turns-off. The amount of time it takes to turn the diode OFF also increases the additional losses in the IGBT. Reflex technology, by keeping the dI/dt constant during the turn-on of the IGBT, compensates for the non-linearity and allows a significant reduction of the switching losses in the diode as well as in the IGBT.

PERFORMANCE OF THE REFLEX GATE DRIVER TECHNOLOGY

This section describes how Reflex Dual Gate Driver Technology improves the performance of the original Reflex Gate Driver by controlling the dV/dt across IGBTs or other power electronic switches. Upon turn-off of the IGBT, the Reflex mechanism only takes place once the current starts to decrease in the IGBT, after its voltage has reached the bus voltage. As described above, the gate-emitter voltage may decrease below the threshold voltage before the current starts to decrease in the IGBT because the input MOSFET is faster than the output transistors.

To eliminate delays before Reflex takes action upon the dI/dt, the gate-emitter voltage should be kept in the linear region. Keeping the gate-emitter voltage in the linear region during the dV/dt would eliminate this delay as the IGBT is in dV/dt state prior to dI/dt. As dV/dt and dI/dt are dual in terms of power electronics elements, the principle of duality was applied to the Reflex Gate Driver Technology to develop to the topology of the Reflex Dual as follows:

- Reflex Gate Driver Technology controls the dI/dt in the IGBT by injecting the voltage across the parasitic emitter inductance (in series with the IGBT) in series with the voltage source of the gate driver power supply.
- Reflex Dual Gate Driver Technology controls the dV/dt across the IGBT by injecting the current in the external collector-gate capacitor (in parallel with the IGBT) in parallel with the current source of the gate driver power supply.

FIGURE 3 shows the dual diagram blocs of **FIGURE 2**. The gate driver incorporating the Reflex/Reflex Dual circuit is configured as a pair of current sources connected to the gate of the IGBT Ion providing the turn-on current and Ioff the turn-off current. The additional capacitor added between the collector and the gate acts as another current source placed in parallel with these two.

Reflex Dual is configured in-circuit to push Reflex Gate Driver Technology further; it allows commutation to speed-up even more by compensating for the non-linearity of IGBTs or other electronic switches.

EXPERIMENTAL RESULTS

FIGURE 4 shows how fast the dV/dt can be without having overvoltage above the IGBT rating, no matter what the output current is. Similarly, the square shape of the overvoltage shows the constant dI/dt reaching the limit of the commutation cell.

The overvoltage that appears in is due to the negative dI/dt upon turn-off of the IGBT; the same behaviour occurs upon turn-on but with an under-voltage that controls the dI/dt. This leads to better performance of the diode and the IGBT.

FIGURE 5 shows a comparison of the output current an HP2 module from Infineon can give as a function of the battery voltage. The two curves were taken in similar conditions: the cooling liquid was at 55 °C, the junction temperature at 130 °C. The two gate drivers were tuned to sustain 2000 A at 450 VDC. The top curve was taken with Reflex Gate Driver Technology and the bottom one without. The gate drivers were tuned to get the maximum dI/dt

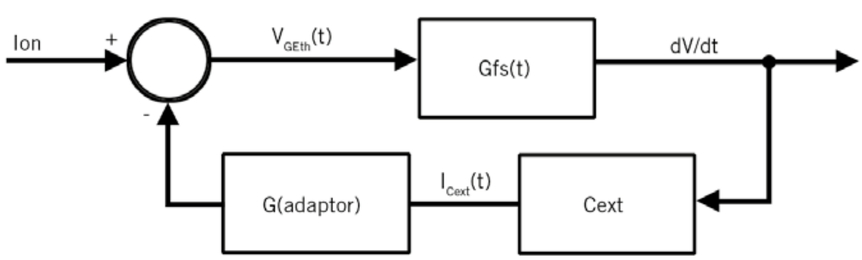

FIGURE 3 Closed loop control of the dI/dt with focus on dual diagram blocs

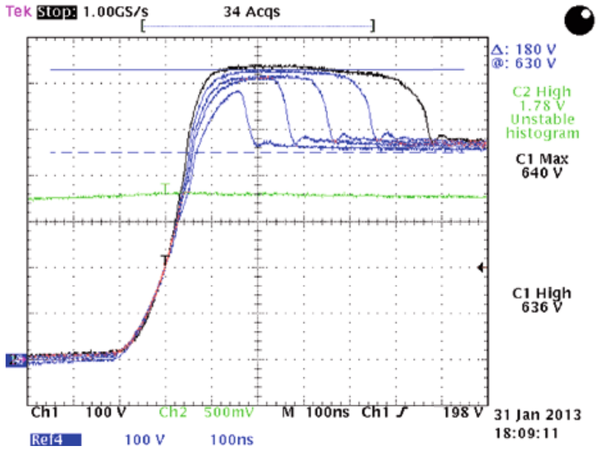

FIGURE 4 Optimised turn-off with Reflex at 450 V: 480 A, 1120 A, 1700 A, 2300 A and 3600 A

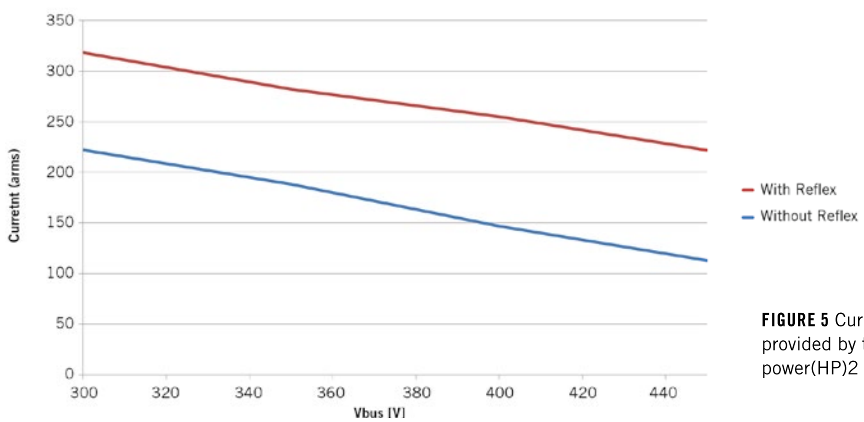

FIGURE 5 Current provided by the High-power(HP)2 at 130 °C

possible without exceeding the IGBT rating. Switching losses increase with the operating voltage and the switching frequency; these curves show that the higher the switching losses are, the better Reflex and Reflex Dual technologies perform.

CONCLUSION

This article has presented an innovative approach to controlling IGBTs or other power electronic switches based on the use of the parasitic elements of the power module, called Reflex Gate Driver Technology. In addition, this article has introduced Reflex Dual, which further pushes the original Reflex Gate Driver Technology by keeping the gate-emitter voltage in the linear region until the dI/dt starts. The dI/dt in the frequency loop of a commutation cell plays a key role in over voltage and efficiency; it can also create an overvoltage above the IGBT rating if it is too high or penalise the efficiency if it is too low.

Using Reflex to limit the dI/dt when the IGBT turns-on allows for optimal behaviour. Controlling the dI/dt also limits the recovery current of the opposite diode. Based on this, it was shown that Reflex Gate Driver Technology reduces the switching losses at turn-on in both the diode and the IGBT. Experimental results have shown how Reflex clamps the overvoltage across the IGBT whatever the current is, giving it a square shape that extends in time and keeps the same amplitude even with the current up to short-circuit conditions. It was also demonstrated that improving switching losses with Reflex may double the output current at high frequency and high-operating voltage.

Reflex/Reflex Dual Gate Driver technologies do not only help to increase the output current achievable with semiconductors, but also make them less sensitive to operating voltage. These technologies control the gate voltage to make it behave as a linear component.

This whole process of switching is well controlled by TM4 and can be adapted to any type of electronic switch.

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