Using Advanced Active Clamping to Facilitate Simple, Safe and Reliable IGBT Driving in Multi-Level Topologies

The Advanced Active Clamping (AAC) functionality implemented in CONCEPT's SCALE™-2 technology allows multi-level converter topology designs to be simply and safely driven. In the event of an IGBT short circuit, all IGBTs no longer have to be turned off in a dedicated sequence to avoid excessive IGBT collector-emitter voltages. Instead, the AAC function limits the maximum collector-emitter voltage of the IGBTs to a safe level, enabling the IGBTs to be simply turned off as soon as the fault condition is detected. This advanced functionality is illustrated using analysis performed on a 2SC0108T2D0-07 (650V/1W/8A) driver core (Figure1).

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Multi-level converters

Multi-level and especially 3-level converters in a neutral-point clamped (NPC) topology (Figure 2 right) are an interesting alternative to 2-level converters (Figure 2 left) in many applications including solar, wind power or traction converters [1]. In solar applications, 3-level converters allow lower voltage IGBT modules to be used to achieve the same output voltage and power. Also, the total harmonic distortion (THD) of the output current and voltage as well as the size of passive components such as output inductors or DC-link capacitors can be reduced. The overall system efficiency can also be optimized.

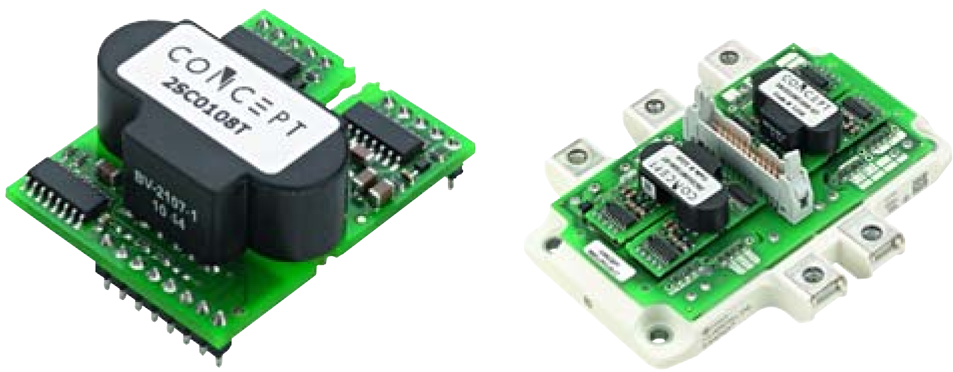

Figure 1: 2SC0108T2D0-07 driver (left) and 2SC0108T2D0-07 driver (right) on a driver board used to drive a 3-level NPC IGBT module

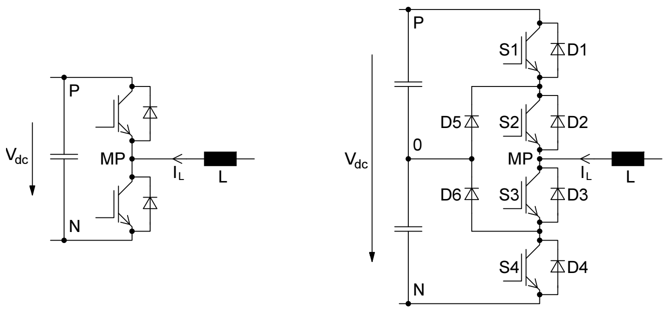

Figure 2: Half-bridge 3-level NPC topology (right) versus half-bridge 2-level topology (left)

However, specific commutation sequences must usually be employed, because the IGBTs are designed to withstand only half of the full DC-link voltage in the off-state. Without the aforementioned specific commutation sequences, the full DC-link voltage may be applied to a single switch, leading to its destruction unless specific counter-measures are used. This is especially likely in the case of an IGBT short circuit. CONCEPT's Advanced Active Clamping functionality – a feature of the company's SCALE-2 technology - efficiently addresses this issue.

Advanced Active Clamping (AAC)

Active Clamping has been widely used for many years to limit the collector-emitter voltage of an IGBT during the turn-off event [2]. The IGBT is partially turned on as soon as its collector-emitter voltage exceeds a pre-defined threshold. The IGBT is then maintained in linear operation, thus reducing the fall rate of the collector current and therefore the collector-emitter over-voltage.

Basic Active Clamping topologies implement a single feedback path from the IGBT's collector through transient voltage suppressors (TVS) to the IGBT gate (see Figure 3 left). In SCALE-2's Advanced Active Clamping (AAC) from CONCEPT, feedback is also provided to the driver's secondary side at pin ACL (see Figure 3 right): as soon as the voltage on the right-hand side of the resistor R1 increases due to the active clamping activity, the turn-off MOSFET of the driver connected to GL is progressively switched off [3]. This reduces the charge that flows away from the IGBT gate to COM over the turn-off gate resistor $R_{g,off}$. The result is a reduced IGBT turn-off over-voltage ΔV_{ce} as well as reduced TVS losses [4].

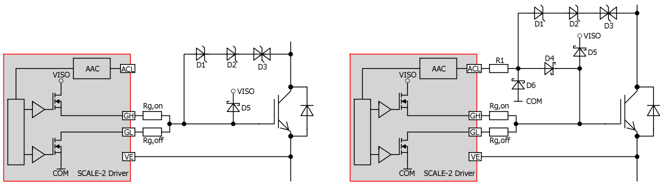

Figure 3: External circuit for Basic Active Clamping (left); Advanced Active Clamping (AAC) using SCALE-2 technology (right)

Effectiveness of AAC in 3-level Topologies

Thanks to the powerful $V_{ce,peak}$ voltage limitation provided by AAC, dedicated turn-off sequences no longer need to be applied in the event of IGBT short-circuits in 3-level or multi-level topologies. As soon as an IGBT driver detects a fault condition (e.g. IGBT short circuit), it turns off the corresponding IGBT module immediately regardless of its position in the converter topology, and a fault signal is transmitted to the user interface within about 450ns. If an incorrect turn-off sequence is then applied, the AAC safely limits the maximum V_{ce} voltage of the corresponding IGBT. The host controller needs only to apply a common turn-off pulse to all IGBTs to avoid thermal overload of the IGBT drivers.

To illustrate this concept, measurements were performed using an Infineon F3L200R07PE4 650V/200A 3-level NPC1 IGBT module with CONCEPT's 2SC0108T2D0-07 SCALE-2 driver. 2SC0108T2D0-07 drivers belong to CONCEPT's 2SC0108T driver family and include the following extra features when compared to the basic 2SC0108T2A0-17:

- AAC is implemented
- The susceptibility to magnetic fields has been dramatically decreased to allow safe operation directly on top of IGBT modules, as shown in Fig. 1, right.
- The reference voltage for desaturation protection is set to a fixed value of 9.3V.

The typical TVS breakdown voltage is set to 479V at 1mA/25°C to allow a maximum DC-link voltage V_{dc} of 870V (both half DC-link voltages are set at the same value for all measurements).

As an example, a short-circuit path is introduced between the middle point MP and the neutral point 0 in the topology of Fig. 2 right. The measurement shown in Fig. 4 is performed with the maximum DC-link voltage V_{dc} of 870V. Initially, all switches are in the off-state (a). IGBT S3 is then turned on (b). The half DC-link voltage of 435V is applied to IGBT S4 (V_{ce4}), and no short-circuit current flows. When S4 is turned on (c), the short-circuit current I_{c4} increases through S3 and S4 until IGBT S3 de-saturates, followed a little later by S4. A dedicated turn-off sequence would require turning off IGBT S4 prior to S3. But in our example, S3 is turned off first (d). Without protective measures, the short-circuit current would commutate to the diodes D1 and D2 in Fig. 2, leading to the full DC-link voltage of around 870V being applied to S3 (V_{ce3}) - considerably exceeding the maximum IGBT voltage capability. Fig. 2 clearly shows the voltage limitation of V_{ce3} to a maximum value of 500V during the full turn-off phase (d). When the short-circuit current is completely turned off, the half DC-link voltage of 435V is applied to IGBT S3 (e).

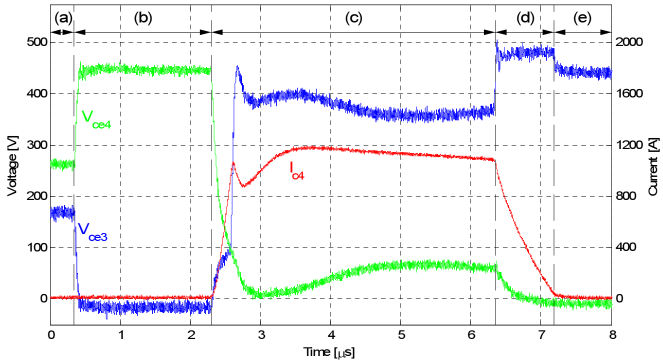

Figure 4: "Incorrect" turn-off sequence during short circuit between MP and 0

Conclusion

SCALE-2 driver cores, such as the 2SC0108T2D0-07, enable highly compact driver designs, and the example clearly demonstrates the effectiveness of the SCALE-2 technology's Advanced Active Clamping feature in limiting the maximum IGBT collector-emitter voltage in 3-level NPC topologies when an incorrect turn-off sequence is applied. Therefore, a dedicated turn-off sequence no longer needs to be applied which simplifies the short-circuit management of multi-level converters and allows standard 2-level IGBT gate drivers to be used in multi-level topologies without any modification or additional circuit elements. The host controller needs only to apply a common turn-off pulse to all IGBTs in the system as soon as an IGBT short-circuit is detected. AAC offers passive and efficient protection against IGBT collector-emitter over-voltages of any kind at any time.

References

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[3] Description and Application Manual for 2SC0108T2Dx, CONCEPT.

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