Advantages of Advanced Active Clamping

Power semiconductor manufacturers are offering IGBT modules with ever greater power densities. The limit is represented by the maximum power loss that can be dissipated; optimisation criteria are the packaging technology as well as the conduction and switching losses of the semiconductor chips. The high current density of the modules together with high switching speeds place increased demands on the driving circuits, both in normal switching operation and under overload conditions. Advanced Active Clamping switching technology offers a solution showing how modern high-power IGBTs can be better utilised. **Heinz Rüedi, Jan Thalheim and Olivier Garcia, CT-Concept Technologie AG, Switzerland**

Parasitic inductances in IGBT modules and converter circuits cannot be completely eliminated for physical reasons, and their influence on the system behaviour cannot be neglected. Figure 1 (upper part) shows the parasitic inductances contained in a commutation circuit. The current change caused by turning off the IGBT produces voltage transients at its collector, as shown in the lower part of Figure 1.

The commutation speed and thus, the turn-off over-voltage at an IGBT can, in principle, be affected by the turn-off gate resistance $R_{g(off)}$. This technique is used particularly at lower powers. However, $R_{g(off)}$ must then be dimensioned for overload conditions such as turn-off of the double rated current, short circuit and a temporarily increased link circuit voltage. In normal operation, this results in increased switching losses and turn-off delays, which reduces the usability of the modules. So this simple method is unsuitable for modern high-power modules.

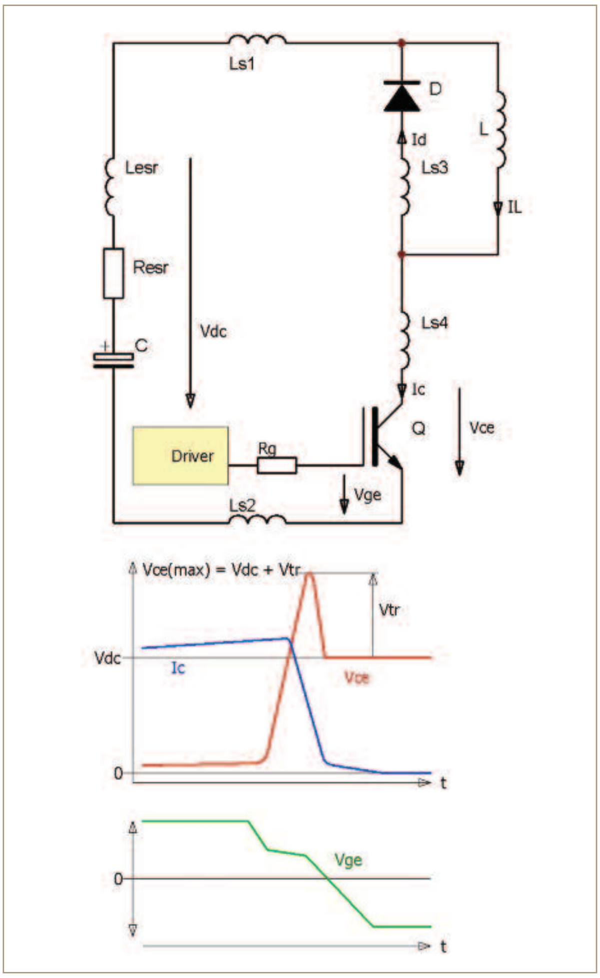


Figure 1: **Commutation circuit with parasitic inductances (above) and typical characteristic at IGBT turn-off (below)**

Soft Turn-Off

The problems described above have led to the development of two-stage turn-off, soft-switch-off, and slow turn-off driver circuits operating with a reversible gate resistance. In normal operation, a low-ohmic gate resistor is used to turn the IGBT off in order to minimise the switching losses, and a high-ohmic one is used when a short circuit or surge current is detected (see Figure 2).

However, the problem lies in the reliable detection of these conditions: desaturation monitoring always involves a delay known as the response time, usually of 4-10µs, until a fault is detected. When the IGBTs are driven with a pulse that is shorter than the response time in the event of a short circuit, the fault is not detected and the driver turns off too quickly. The IGBT is then destroyed by the resulting over-voltage.

Moreover, coverage of limit cases (between over-current/non-over-current) presents a problem; for instance a higher over-voltage may well occur when the double rated current is turned off than at a short-circuit turn-off.

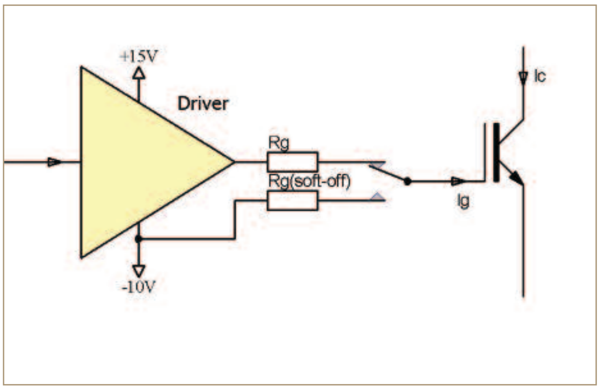
These kinds of driver circuits must be regarded as dangerous and users must be advised against their use in equipment of higher power and in systems from which high reliability is expected.

Apart from that, a soft turn-off circuit designed for only two operating conditions is clearly unable to ensure optimal driving at all times under changing operating conditions. Consequently, this principle is, at best, a compromise, also with respect to efficiency.

Active Clamping

Simple Active Clamping has already

Figure 2: Principle of an IGBT driver with soft turn-off



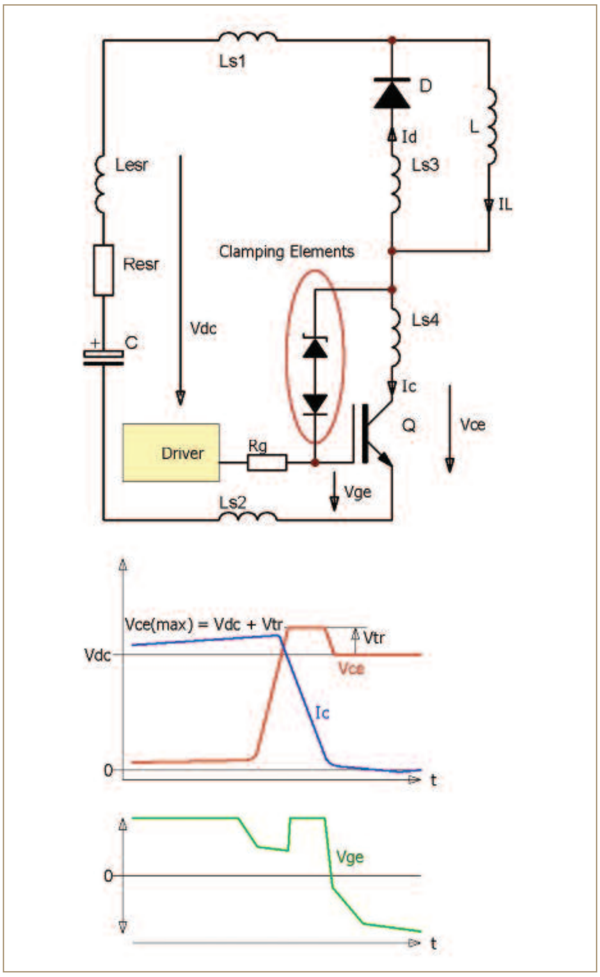


Figure 3: Principle of an IGBT driver with Active Clamping (above) and typical characteristic at turn-off with Active Clamping (below)

been used for some time to protect power MOSFETs. Active clamping means the direct feedback of the collector potential to the gate via an element with an avalanche characteristic. Figure 3 (upper part) shows the principle on the basis of an IGBT switch.

The feedback branch consists of a clamping element, as a rule comprising a series of transient voltage suppressors (TVS). If the collector-emitter voltage exceeds the approximate breakdown voltage of the clamping element, a current flows via the feedback to the gate of the IGBT and raises its potential, so that the rate of change of the collector current is reduced and a stable condition results. The voltage across the IGBT is then determined by the design of the clamping element. The IGBT operates in the active range of its output characteristic and converts the energy stored in the stray inductance into heat. The clamping process continues until the stray inductances have been demagnetised. The fundamental relationships involved here on the basis of typical curves are illustrated in the lower part of Figure 3.

Benefits of Active Clamping:

- Self-adapting system, comes into action only when really needed
- Lower switching losses
- Simple circuit configuration
- The IGBT to be protected is itself a major part of the protective circuit
- No additional power components (snubbers) required
- Relatively exact voltage limitation independent of the operating point of the converter
- Conventional drivers can be used

Active Clamping offers more reliable protection of the IGBTs than a soft turn-off circuit, does not require the detection of a fault case, and offers higher efficiency.

Advanced Active Clamping

Simple Active Clamping is traditionally used only to protect the semiconductor in the event of overload. Consequently, the clamping elements are never subjected to recurrent pulse operation.

The problem of repetitive operation takes the following form: modern high-power IGBTs are optimally driven with gate resistors in the range from 0.1 to several ohms. For turn-off, the driver supplies an output voltage of –10V. However, the Active Clamping Circuit must raise the gate voltage temporarily to about +15V, in order to reduce the rate of current change. This produces a voltage drop of 25V across the gate resistor. A high current is absorbed by the driver, which flows through the Active Clamping circuit, where it produces high losses and additional voltage drops. The simple Active Clamping circuit is consequently unsuitable for repetitive operation.

An improved Active Clamping circuit has been presented with a plug-and-play driver for IHM modules [1]. The circuit principle is shown in Figure 4. Here, the base of the chain of clamping diodes is, as usual, connected to the gate of the IGBT, but additionally to the input of a booster stage. The driver voltage is consequently raised as soon as a current flows through the clamping element. The driver stage now no longer draws any current from the clamping element, and the current flowing through the latter is then available exclusively for charging the gate. The voltage drop and power loss in the clamping diodes can thus be dramatically reduced. This circuit has proved its worth in the first generation of SCALE plug-and-play drivers used in a large number of industrial and traction applications.

SCALE-2 Integrated Advanced Active Clamping

The SCALE-2 generation [2] offers Advanced Active Clamping functionality not only in plug-and-play drivers but also in driver cores. Figure 5 illustrates this with the circuit of the SCALE-2 2SC0435T low-cost driver core with the use of the Advanced Active Clamping function.

The base of the clamping elements is

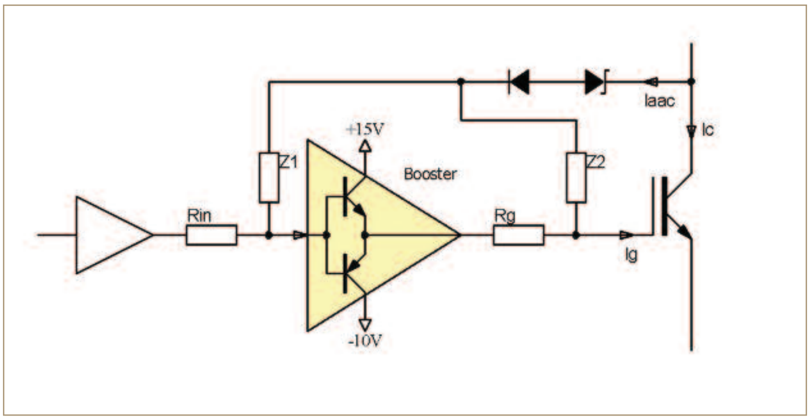


Figure 4: Principle of an IGBT driver with Advanced Active Clamping

connected not only to the gate of the IGBT, but also to the ACL input of the SCALE-2 driver ASIC. The gate driver ASICs implemented in sophisticated fast analog CMOS technology continuously raise the output resistance of the turn-off driver stage as the current to the ACL input increases. When the current reaches several 100mA, the output stage has high impedance, so that the driver no longer absorbs any current from the clamping element. This circuit operates more efficiently than the discretely implemented solution shown in Figure 4, uses significantly fewer components and is very simple and safe for the user.

Figure 6 shows the turn-off behaviour of the 2SP0320T plug-and-play driver with an IGBT module FF450R12IE4 using the same SCALE-2 circuit technology with Advanced Active Clamping.

The Advanced Active Clamping integrated in the SCALE-2 chipset has – in addition to all the advantages of the simple Active Clamping solutions – the following benefits:

- Simple scalability in the voltage class
- Low thermal load of the clamping elements
- Very low-ohmic gate resistors possible
- Steep limiting characteristic
- Suitable for all modern high-power IGBT modules
- Periodic operation possible
- Minimum switching losses
- Improved system performance
- Self-adapting system, acts only when really needed
- Can be configured simply and safely
- Very competitive system costs

Conclusion

Advanced Active Clamping is one of the most important features of a modern driver for high-power IGBTs. The circuit not only protects the IGBT in the event of a fault, it is also the precondition for allowing the optimal utilisation of IGBT modules with high power densities. Integration by sophisticated analog or mixed-signal ASIC technologies allows the simple and cost-effective implementation of Advanced Active Clamping with very few components.

Drivers with Advanced Active Clamping are offered as ready adapted plug-and-play drivers and in the form of driver cores. The latter allow the user to adapt the circuitry to his requirements.

Outlook

The benefits of Advanced Active Clamping for direct parallel connection of IGBT modules, as well as in multilevel topologies, will be presented in the January 2010 issue of PEE. The integration of dv/dt feedback will also be covered.

Literature

[1] Heinz Rüedi, Peter Köhli: 'SCALE' Driver for High Voltage IGBTs, PCIM Europe Conference Proceedings Nuremberg, 1999

[2] Jan Thalheim, Heinz Rüedi: Universal Chipset for IGBT and Power-MOSFET Gate Drivers, PCIM Europe Conference Proceedings Nuremberg, 2007

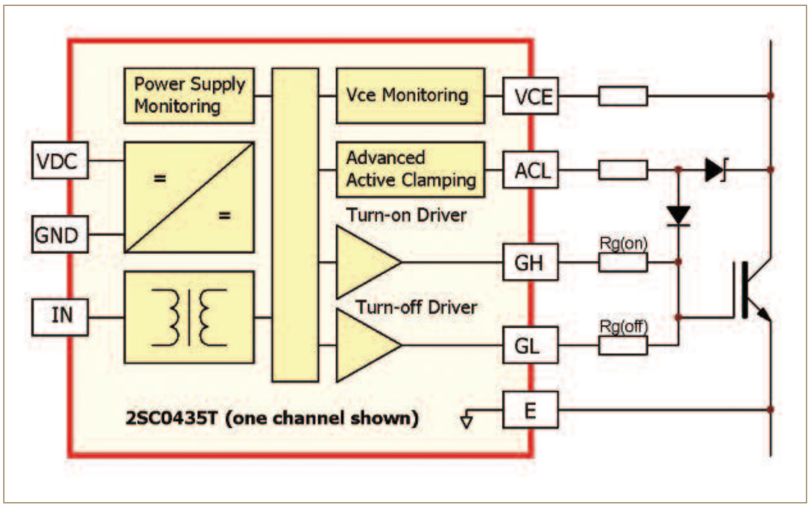


Figure 5: SCALE-2 Integration of Advanced Active Clamping illustrated by the 2SC0435T driver core

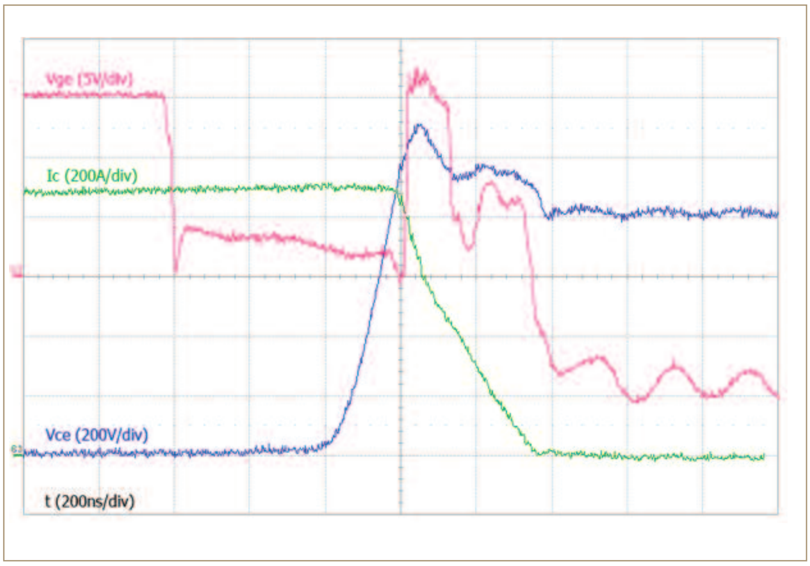


Figure 6: Switching behaviour of a FF450R12IE4 IGBT with the 2SP0320T (with Advanced Active Clamping) at V_{dc} = 800V and I_c = 900A, L_{stray} = 68nH, Temp = +25°C