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Intelligent Paralleling

A new approach to paralleling IGBT modules with individual drivers

A gate driver for PrimePACK™ IGBTs designed for high item numbers allows optimal driving of single and parallel-connected modules. This makes it possible for the first time to construct converter series with both single modules and parallel-connected IGBTs practically with no additional development effort. Despite the typically smaller item numbers associated with increasing converter powers, users benefit from the performance, quality and reliability as well as the favourable manufacturing costs of this driver optimised for large series.

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Infineon presents compact IGBT modules for industrial and traction applications with its PrimePACK™ series. These low-inductance half-bridge modules allow efficient high-power converters to be constructed more simply than with single IGBT modules. The half-bridge configuration and long, narrow design of the PrimePACK modules almost invites their simple parallel connection in order to achieve powers in the megawatt range.

Conventional drives

Parallel-connected IGBTs are conventionally driven by a common driver, with individual gate and emitter resistors for each IGBT. However, modules of the PrimePACK power class require more extensive circuitry: they cannot, for instance, dispense with active clamping [1], which results in solutions such as that proposed in Figure 1.

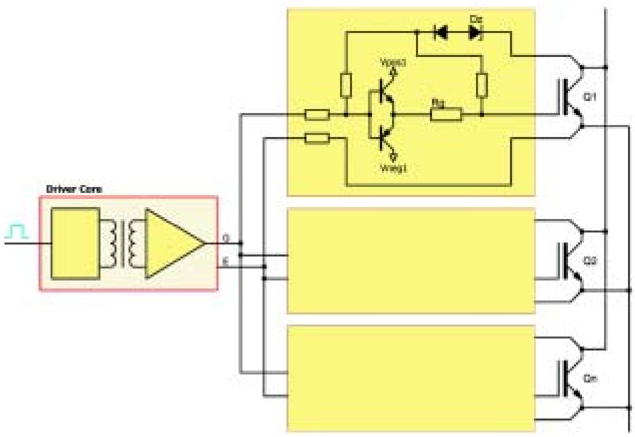

Figure 1: Principle of a central driver extended by active clamping

As converter manufacturers are often obliged to offer systems of various powers, this solution has two drawbacks: the driver circuit must be individually optimised for each power class – which is a time-consuming process, and a wide diversity of types results.

New driver solution

An alternative approach to driving parallel-connected IGBT modules is to use an individual driver for each module, as shown in Figure 2. However, this attractively simple approach was hardly practical in the past because the drivers previously available on the market had excessive runtime differences and jitter, which would have led to an asymmetrical distribution of the collector currents and losses in the parallel-connected modules. Moreover, previous drivers also failed to offer any scenario for the behaviour of parallel-connected drivers in the event of a fault.

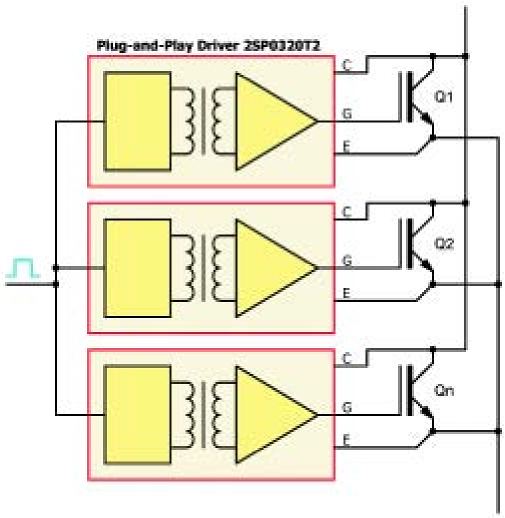

Figure 2: Principle of driving parallel-connected IGBTs with individual drivers

A solution is now available with the SCALE-2 driver chipset from CONCEPT [2] [3]. With a runtime of just below 80ns, it is about five times as fast as the preceding generation and 8 to 20 times faster than typical competitor solutions. In addition, the small deviations in the runtimes of the various drivers of <±4ns and the extremely low jitter of <±2ns make it ideal for use in the parallel circuit. The low tolerance of these parameters ensures that the parallel-driven IGBTs switch almost simultaneously.

A plug-and-play driver solution for PrimePACK modules was developed on the basis of the SCALE-2 chipset [4] [5]. The 2SP0320T2 family comprises complete and compact dual-IGBT drivers equipped with DC/DC converters, short-circuit protection, advanced active clamping and monitoring of supply under-voltages (see Figure 3).

Symmetry in normal switching operation
The DC/DC converters contained in the drivers supply such accurate output voltages that differences in the gate voltages produce hardly any asymmetries relevant to the application. Moreover, investigations also showed that the asymmetry of the collector currents also remains at a similarly low level thanks to the runtime differences possible with this driver. On the whole, the redistribution of the IGBT currents due to the driver tolerances is practically negligible. On top of that, asymmetries due to the mechanical configuration as well as component tolerances will have a far greater influence in most real equipment designs.

As every IGBT module has its own driver, the power of a single driver does not need to be distributed over several IGBTs. So this concept also allows high clock frequencies with parallel circuits.

In principle, this method can be used to drive any number of modules in parallel. In the case of very massive parallel circuits – apart from a symmetrical configuration – it is only necessary to control the distribution of the diode currents. If required, this can be facilitated by adding inductors to the phase feed lines of the individual modules.

Behaviour in the case of faults and short circuits
After considering normal switching behaviour, the question arises as to how the system will behave in the case of abnormal operating conditions.

The conditions during the build-up and drop of the voltage supply present no problems, as every SCALE-2 chip – on both the primary and secondary sides – contains its own under-voltage detection. The gate-driver chips on the secondary side report the fault conditions back to the primary-side chips via the transformers. The status messages are combined on the user side and show when all systems are operational.

A short circuit is detected by the desaturation monitoring contained in each driver within a typical time of 4.4µs. The SCALE-2 chipset in the 2SP0320T2 operates in a special mode, transmitting the fault within 450ns to the primary side even before the IGBT has been turned off by the driver. The user controller then has enough time to generate a turn-off command and turn all IGBTs off simultaneously. The behaviour of the entire system in this case is no different than if all the IGBTs were driven by a central driver.

However, if no turn-off command is generated on the user side, each driver automatically switches off its associated IGBT 3.6µs after detecting a short circuit. But as this time is subject to tolerances and the desaturation monitoring of each driver does not necessarily detect the short circuit exactly at the same time, it can be assumed that the individual IGBTs will not turn off exactly simultaneously.

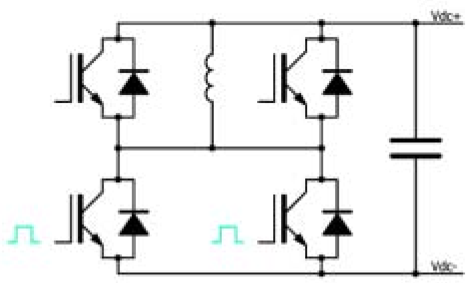

Figure 4: Test circuit for short-circuit measurements

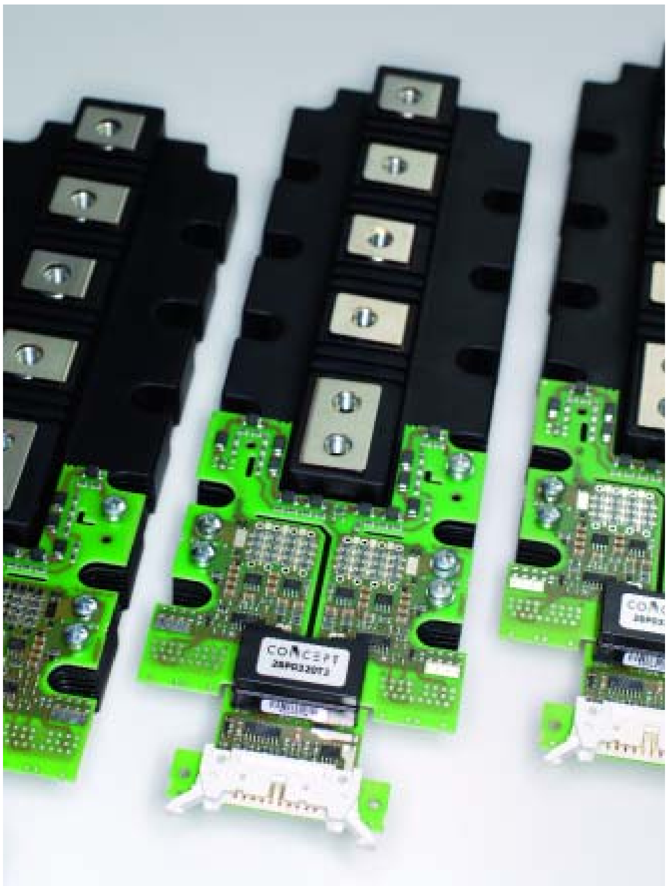

Figure 3: The 2SP0320T2 driver, suited for single and parallel connected modules

Moreover, a case is conceivable which may be rare in statistical terms but can nevertheless occur under certain circumstances: the command to turn an IGBT off is transferred via the transformer interface at exactly the same time as the driver chip reports a short circuit that it has just detected. The collision of the signals and the priority of the error feedback causes the corresponding channel not to detect the turn-off command, while the other drivers initiate the turn-off sequence. As a consequence, the corresponding IGBT turns off with a delay.

In a test set-up shown in Figure 4, it was examined how parallel-connected PrimePACK IGBT modules behave when they are turned off simultaneously or with a time delay, both in a low inductance short circuit and with short-circuit inductances up to 2µH.

Whereas we have already seen that the synchronous short-circuit turn-off presents no problems as expected (see Figure 5), the behaviour of the system is also completely safe in the case of sequential turn-off of the IGBTs after a short circuit, as can be seen in Figure 6. After turn-off of the first IGBT, the second IGBT, which is still in the short circuit, acts as a constant current source and cannot absorb any additional current, so that only its collector-emitter voltage increases somewhat.

The freewheeling diode of the first IGBT to be turned off must absorb the full short-circuit current that had previously flowed through the opposite IGBT in the same module. The freewheeling diode of the IGBT that is turned-off later absorbs this current when it subsequently commutates. The amplitudes of the turn-off overvoltages are somewhat lower than the corresponding overvoltage resulting from both

IGBTs being turned off synchronously. This is understandable, because at a given intermediate circuit inductance only a partial current is momentarily commuted in the first case, while the entire current is commuted at once in the other case.

Interface

In principle, all lines of the driver interface can be simply connected in parallel if an individual fault detection is of no interest. If more detailed error detection is required, then only two status signals per driver have to be individually evaluated, while all the other lines can be connected directly in parallel.

It's highly recommended to use the same voltage supply for all drivers, so that they all operate with identical gate voltages. Moreover, it is advisable to run the connecting cables to all the drivers with identical lengths and to dispense with daisy-chain cabling. These two measures ensure an optimal symmetry from the viewpoint of the drivers. It is then only important to ensure that the power layout is as symmetrical as possible.

Benefits and drawbacks

This solution has the following advantages:

- Both single and parallel-connected PrimePACK modules can be driven
- Simplest scaling of output
- Uncompromising, safe and reliable concept
- No limit to the number of parallel-connected IGBTs
- Optimal switching behaviour, lowest switching losses
- High clock frequencies also for parallel circuits
- Detailed diagnosis as required: one status per driver / IGBT
- No coupling of the gates, thus no mutual oscillations of the IGBTs possible
- No effects of the capacitive equalising currents flowing away via the module baseplate
- No effects of inductive coupling on the gate cabling
- No complex synchronisation needed
- Equipment series can be simply extended to parallel connection, also subsequently
- No development effort, no adaptation work
- Simple to set up, no tangle of cables
- Minimal derating and maximum utilisation of the IGBT modules
- Use of optimised large-series system components
- Simple logistics, one driver for the entire converter series

At first sight, it might seem a disadvantage to have several chipsets and transformers (a set for each IGBT module), whereas the conventional approach with a central driver needs only one set. However, this apparent disadvantage is very quickly relativized in view of the fact that these components are also highly optimised in terms of costs. If a central driver has to drive several IGBTs, then its transformer, the output stage and the blocking capacitors etc. will need to have correspondingly higher ratings. The outlay for active clamping is in any case the same for both solutions, whereas the 2SP0320T2 approach can manage with fewer components (gate and emitter resistors, supply decoupling etc.). Moreover, the new solution dispenses with the various circuit boards, connectors and cables of a conventional solution, which carry a high voltage and must be carefully configured to prevent the occurrence of major asymmetries.

Conclusion and outlook

The new solution for parallel-connected IGBTs with individual drivers promises much: even after careful observation, its numerous obvious benefits are not countered by a single serious drawback. From the driving aspect, the concept does not limit the number of parallel-connected IGBT modules.

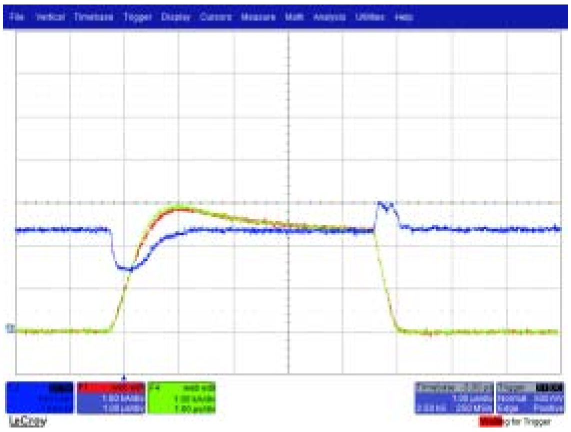

Figure 5: Synchronous turn-off of parallel-connected IGBTs in low-inductance short circuit

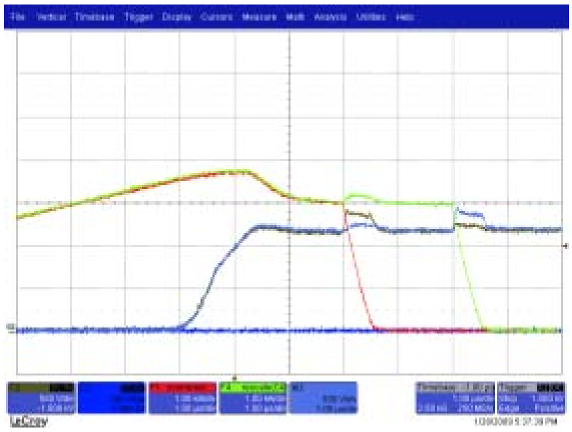

Figure 6: Sequential turn-off of parallel-connected IGBTs with 2μH short circuit inductance

The parallel-connection concept will also be transferrable to 3.3kV IGBTs as soon as these are available as PrimePACK modules. This will mean that complex converter designs and expensive driving solutions will soon belong to the past in this voltage class too.

As this solution can also be applied to all (future) transformer-based SCALE-2 driver cores, use of the concept described here is not restricted to PrimePACK modules but may be transferred to all other half-bridge IGBT modules.

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