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OPTIMIZED RENEWABLE INVERTER SYSTEMS

SCALE™-2 IGBT Gate Drivers Ease the Design of Optimized Renewable Inverter Systems

The 2SP0325 IGBT gate driver – a member of the SCALE™-2 plug-and-play gate drivers from CONCEPT – allows New Mega Power Dual IGBT modules from Mitsubishi to be driven efficiently in solar and wind power applications. The driver facilitates compact and reliable power converter design thanks to its high level of integration and robustness to EMI, resulting in a flexible and ready-to-use solution.

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The growing market for renewable energy requires powerful IGBT modules for use in solar and wind mill inverters. Ideally, the number of IGBT modules required must be kept to a minimum to reduce system costs and complexity while keeping the reliability at a high level. In response, Mitsubishi has released its New Mega Power Dual, an IGBT module family which uses half-bridge topology for three-phase converters in the MW range without requiring parallel connection of IGBT modules. Two types are available: a 1200V/2500A designed especially for solar inverters (CM2500DY-24S), and a 1700V/1800A module for wind mill inverters (CM1800DY-34S). The IGBT modules have been optimized using CSTBT™ (Carrier Stored Trench Bipolar Transistor) technology combined with a very low inductive internal wiring and a sophisticated aluminum baseplate to optimize module cooling [1].

Figure 1: 2SP0325T screwed onto a New Mega Power Dual IGBT module

This article describes the main functionality of the 2SP0325 SCALE™-2 driver which has been designed to drive the New Mega Power Dual IGBT modules. The driver family comprises two main versions:

- 2SP0325T drivers feature an electrical interface. They are cost-efficient and target cost-sensitive applications.
- 2SP0325V drivers include a fiber-optic interface for applications where this is a requirement.

Both driver versions are safe, compact and reliable solutions that allow short converter design cycles to be achieved.

Design for harsh EMI environments

The gate driver is a key element in achieving a compact and highly-reliable solar or wind power inverter. The driver controls not only the switching characteristics and the associated performance of the converter system, but is also responsible for ensuring that the IGBT switches within safe operating limits, even in the event of an overload or short circuit.

The IGBT module's internal inductance is kept relatively low thanks to a bus bar placed lengthwise along the module, directly under the 2SP0325 driver. Induced electromagnetic interference (EMI) on the driver under normal operation is relatively low, because the current changes in the bus bar happen in both directions, resulting in a small external magnetic field which is typically not a problem for driver electronics placed directly above the IGBT module. However, in the case of an IGBT short-circuit, the magnetic field changes are much higher due to the high currents flowing in the IGBT modules. One crucial task of an IGBT driver is to be able to turn-off reliably within a short time (<10µs) if there is a short circuit. The driver design must, therefore, be optimized to allow operation even at locations with high magnetic fields, specifically to allow for the instance of an IGBT short circuit.

Significant consideration was given to the layout of the 2SP0325 to ensure proper shielding of the driver's electronics with corresponding planes, as well as to optimally cool the components with associated higher power losses, resulting in a lower operating temperature and correspondingly higher reliability. The electrical version (2SP0325T) has been designed for 15V logic to further increase the signal-to-noise ratio of the driver. The choice of the discrete components was carefully made to guarantee a long lifetime and high reliability. As an example, no electrolytic capacitors are used on CONCEPT products.

The highly-integrated SCALE-2 chipset together with the optimizations discussed allow the driver to be operated safely directly on top of an IGBT module without the use of any shielding plates between IGBT module and driver.

Proven SCALE-2 Technology

The SCALE-2 chipset integrates the full functionality of a dual-channel gate driver core in a primary-side chip LDI (Logic to Driver Interface) and a secondary-side chip IGD (Intelligent Gate Driver). Thanks to the high integration level of the chipset, the number of discrete components can be drastically reduced, resulting in cost and reliability advantages.[2]

The primary-side ASIC LDI fulfils the following main tasks:
- The input signals are converted to transformer pulses (electrical interface).
- The fault signals generated by the driver's secondary side are communicated to the driver's primary interface. If there is a fault, the driver remains blocked during the "blocking time" (the corresponding driver's channel remains in off-state).
- The switching signals for the DC/DC converter are generated.
- The primary-side power supply is monitored. In case of supply-under-voltage, both driver channels are turned off and a fault signal is generated.
- Two operation modes can be selected: In direct mode the user can control both driver channels independently (dead times must be generated externally). In half-bridge mode, the LDI generates the dead time between both channels automatically.

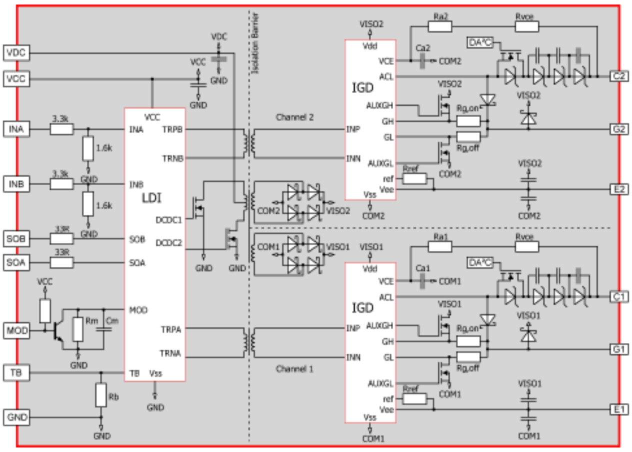

Figure 2: Block diagram of the 2SP0325T SCALE-2 driver

The secondary-side ASIC IGD provides the following functions:
- Transformer signals are converted in +15V/-10V gate-emitter voltages.
- Short-circuit monitoring - during a short circuit, the corresponding IGBT is turned off and a fault is communicated to the primary-side interface.
- Advanced Active Clamping (explained in more detail later in the article) limits the Vce turn-off overvoltage.
- The driver's secondary-side power supply voltages are monitored. The IGBTs are turned off safely in case of supply under-voltages and a fault signal is generated and transmitted back to the driver's primary side (electrical interface).

The DC-DC transformer required to transfer the energy for the gate driver to the secondary sides is also built in to the driver. DC-DC converter and signal transformers both feature safe insulation to EN50178 protection class II between the driver's primary and either secondary side.

Flexible solution

Because the 2SP0325 driver uses the SCALE-2 chipset which includes monitoring and controlling features it is not necessary to assemble any customer specific components like gate resistors: the driver is able to handle a wide range of stray inductances of up to over 35nH. Users only need to supply the driver with 15V non-isolated supply voltage and to provide the corresponding input signals (electrical or fibre-optic connectors) to the gate driver.

Advanced Active Clamping

A key feature of the IGBT driver 2SP0325 is the control of the IGBT turn-off over-voltage. The challenge when designing a ready-to-use driver is to setup the driver's parameters so that they fit a wide range of converter systems without changing gate resistors or other driver parameters.

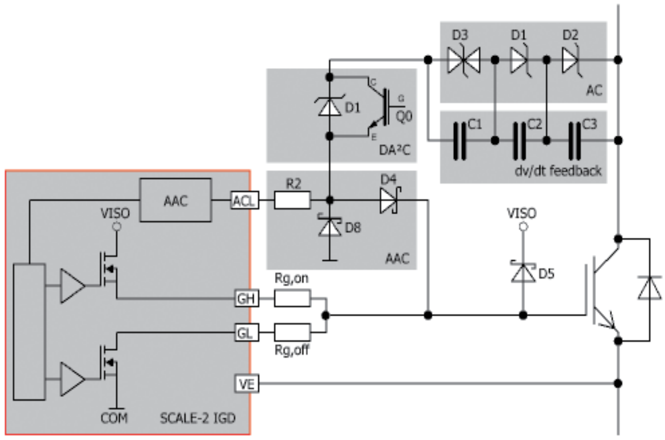

Figure 3: Dynamic Advanced Active Clamping with dv/dt feedback

The well-understood Basic Active Clamping (box AC in Figure 3) limits the collector-emitter voltage of an IGBT during the turn-off event. This clamping topology implements a single feedback path from the IGBT collector through transient voltage suppressors (TVS) to the IGBT gate. The IGBT is partially turned on as soon as its collector-emitter voltage exceeds a predefined 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.

In SCALE-2 technology, Advanced Active Clamping (AAC) feedback (box AC and AAC in Figure 3) operates on the driver's secondary side ASIC. As soon as the voltage increases due to the active clamping activity, the turn-off MOSFET of the driver connected to GL is progressively switched off. This reduces the charge that flows away from the IGBT gate to COM over the turn-off gate resistor Rg,off. This results in a reduced IGBT turn-off collector-emitter over-voltage as well as reduced power losses in the TVS [3].

dv/dt feedback

A dv/dt feedback function (box dv/dt feedback in Figure 3) is additionally implemented in the 2SP0325 drivers. The purpose is to achieve a very efficient turn-off over-voltage limitation during regular switching operation without thermally overloading the TVS. During the collector-emitter voltage rise, a current, defined by the equation i=C· dv/dt, flows in the dv/dt capacitors applied parallel to the TVS. This current further supports the Advanced Active Clamping, as it flows to the same driver's terminal, but is applied sequentially prior to the Advanced Active Clamping feedback. With this additional driving method, the V_{CE} voltage clamping is more effective and the losses generated in the TVS are reduced. The IGBT switching frequency can therefore be increased or it is possible to switch an IGBT module with higher DC-link stray inductances without exceeding the module's Reverse Bias Safe Operating Area (RBSOA). Also, snubber capacitors are not necessary.

Turn-off measurements of CM2500DY-24S IGBT modules with different collector currents and DC-link stray inductances L_σ show the benefits of the SCALE-2 technology. The Advanced Active Clamping and the dv/dt feedback control the turn-off switching to the maximum possible speed without exceeding the RBSOA. This is clearly visible in the measurements for turn-off peak overvoltage for nominal current in Figure 4 ($V_{ce,peak}$=1086V @ L_σ=15nH, $V_{ce,peak}$=1090V @ L_σ=30nH) and double nominal current in Figure 5 ($V_{ce,peak}$=1097V @ L_σ=15nH, $V_{ce,peak}$=1085V @ L_σ=30nH) which show nearly the same results. The oscillation on the gate-emitter voltage is related to the control feedback of the clamping circuit and is fully normal. At the beginning of the collector-emitter dv/dt phase, the gate-emitter voltage increase related to the dv/dt feedback can clearly be seen. In the second part the gate-emitter voltage increase is related to the high turn-off di/dt of the collector current which activates the Advanced Active Clamping functionality.

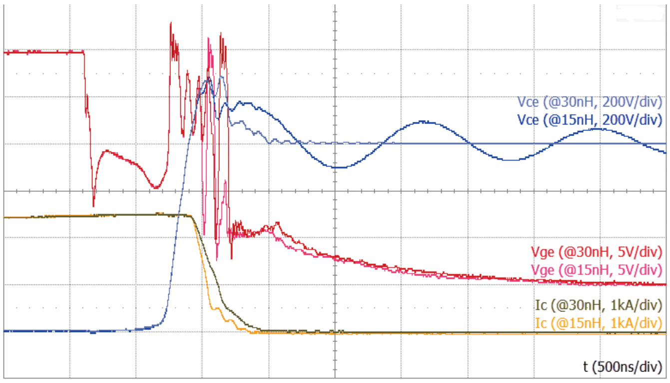

Figure 4: Turn-off comparison of CM2500DY-24S with L_σ=15nH and 30nH (I_C=2500A, V_{DC}=800V, T_A=25°C)

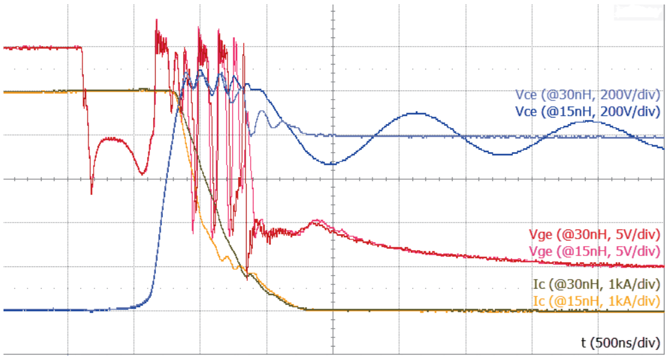

Figure 5: Turn-off comparison of CM2500DY-24S with L_σ=15nH and 30nH (I_C=5000A, V_{DC}=800V, T_A=25°C)

The measurements were performed using double pulse measurement methods in a half-bridge configuration with a CM2500DY-24S driven by 2SP0325T IGBT gate driver. Specific 1µF/1250V snubber capacitors were used to minimize the stray inductance down to 15nH. The results show that the driver can handle currents up to double the nominal current of the IGBT module with full DC-link voltage of V_{DC}=800V.

The measured turn-off overvoltage is lower than the permitted 1200V with sufficient safety margin. The measurements of Figure 4 and Figure 5 were performed at 25°C. The V_{CE} turn-off over-voltages are up to 60V higher at 85°C ambient temperature (maximum allowed ambient temperature of the gate driver), but still clearly remain inside the IGBT module RBSOA.

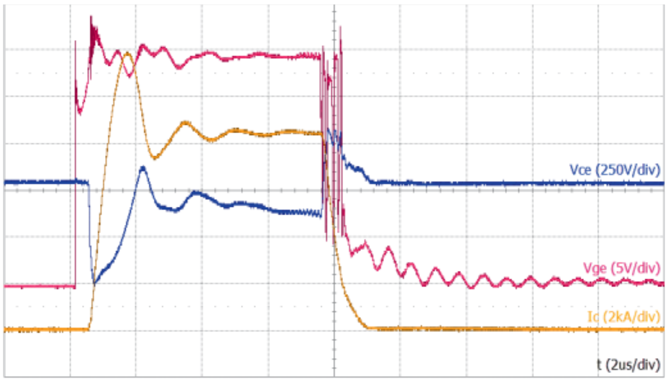

Figure 6: Half-bridge short-circuit with 2SP0325T and CM2500DY-24S

Dynamic Advanced Active Clamping

CONCEPT's Dynamic Advanced Active Clamping (DA²C) is a further development, implemented on 2SP0325 drivers. An additional TVS (box DA²C in Figure 3) is added in series to the TVS used for Advanced Active Clamping. This TVS is short-circuited with an auxiliary IGBT Q0 during the IGBT on-state as well as for about 15-20µs after the IGBT turn-off command to guarantee efficient active clamping (the additional TVS is not active during IGBT turn-off). After this delay, the auxiliary IGBT Q0 is turned-off. The additional TVS is therefore activated and allows the DC-link voltage to be increased to a higher value during the IGBT off-state. This allows, for instance, the possibility to demagnetize the output inductors of the converter system after emergency shut-down, leading to an inevitable short-time DC-link voltage increase.

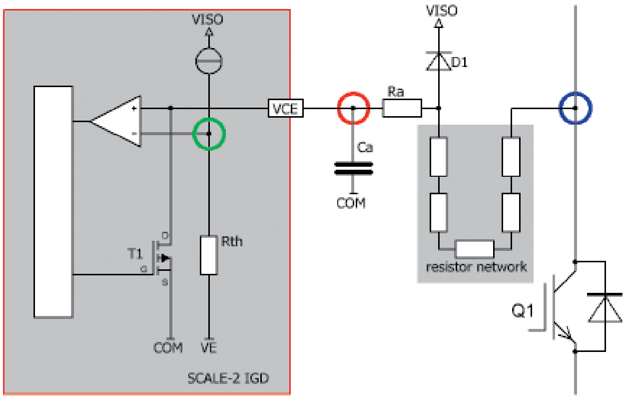

Figure 7: Circuit for short-circuit detection

IGBT Short-Circuit Protection

Short-circuit detection in 2SP0325 drivers is achieved using the same tried-and-tested principle as other SCALE-2 drivers: the saturation voltage of the IGBT during IGBT on-state is monitored with a resistor network. The circuit checks if the collector-emitter voltage has dropped below a pre-defined level in a given time period after the turn-on event. If the collector-emitter voltage does not fall below that level, or later rises above this level during IGBT on-state, a short-circuit condition is detected and the driver will safely turn-off the IGBT within its RBSOA.

During IGBT off-state, the driver's internal MOSFET T1 of Figure 7 connects pin VCE to pin COM. The capacitor Ca is then discharged to the negative supply voltage. At IGBT turn-on and in the on-state, the driver's internal MOSFET T1 is turned off. If the collector-emitter voltage (blue circle) is over the pre-defined level, Ca is charged from the COM potential to the IGBT saturation voltage. If the voltage of Ca (red circle) rises above the level of the reference voltage (green circle), the IGBT is in short-circuit condition and the driver will turn-off the IGBT immediately to protect it against thermal overload.

The desaturation protection function using a resistor network provides further advantages over a standard solution using diodes. Direct V_{CE} sensing is no longer influenced by parasitic capacitances of the high voltage diodes or their pronounced temperature-dependency. Additionally, the filtering time constant during IGBT saturated protection is relatively high – in the range of 50µs. This filtering prevents unnecessary protection regimes being applied in the case of short, abrupt increases of V_{CE} during IGBT on-state.

Moreover, the SCALE-2 drivers provide a tightly regulated V_{CE}+15V gate voltage during IGBT on-state. This feature is particularly advantageous in Type II short-circuit conditions. The high collector-emitter dv/dt values occurring in this failure mode inject considerable amounts of charge into the gate circuit (Miller feedback). This causes the gate voltage to rise, resulting in excessively high levels of short-circuit current. This may lead to a dangerous situation for the IGBT module, especially if the short-circuit time is too long. SCALE-2 drivers use a Schottky diode clamp to limit the gate-emitter voltage to safe values. The stable 15V supply absorbs the Miller feedback charge and safe operation of the IGBT is maintained.

Conclusion

Thanks to the SCALE-2 chipset and high levels of integration, the 2SP0325 CONCEPT gate driver is a cost-effective and reliable solution to drive the New Mega Power Dual IGBT modules from Mitsubishi. The driver has been optimized to cover the requirements of most of the IGBT's applications. The ready-to-use solution allows immediate operation after mounting the driver onto the IGBT module. Short design cycles with low development risks can therefore easily be achieved. With a plug-and-play driver family for the New Mega Power Dual IGBT modules, CONCEPT has again demonstrated the excellent performance of the proven SCALE-2 chipset which enables the optimized operation of the latest generation of IGBT modules in environments with high EMI.

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