Powering IGBT Gate Drives with DC/DC Converters

IGBTs can now be found in high power devices with effective gate capacitances measured in hundreds of nanofarads. Although this capacitance has simply to be charged and discharged to turn the IGBT on and off, the circulating current to do so causes significant power dissipation in voltage drops in the gate driver circuit and within the IGBT. An emerging trend is to use a DC/DC converter to provide optimum power rails for driving IGBTs .**Paul Lee – Director of Business Development, Murata Power Solutions, UK**

At high power, inverters or converters typically use 'bridge' configurations to generate line-frequency AC or to provide bi-directional PWM drive to motors, transformers or other loads. Bridge circuits include IGBTs whose emitters are switching nodes at high voltage and high frequency so the gate drive PWM signal and associated drive power rails, which use the emitter as a reference, have to be 'floating' with respect to system ground, so called 'high side' drives. Additional requirements are that the drive circuit should be immune to the high 'dV/dt' of the switch node and have a very low coupling capacitance. An emerging trend is to use a DC/DC converter to provide optimum power rails for these 'floating' drive circuits using an IGBT.

Typical Example

An initial consideration is to set the on and off-state gate voltages. For example, a typical IGBT is the FZ400R12KE4 from Infineon. It has a minimum turn-on threshold of 5.2 V at 25°C, in practice to ensure full saturation and rated collector current of 400 A, at least 10 V must be applied. The part has a maximum gate voltage of ± 20 V so +15 V is a good value with some margin. Higher values produce unnecessary dissipation in the gate drive circuit. For the off-state, 0 V on the gate can be adequate. However, a negative voltage typically between -5 and -10 V enables rapid switching controlled by a gate resistor. A consideration also is that any emitter inductance between the IGBT and the driver reference, (point x in Figure 1), causes an opposing gate-emitter voltage when the IGBT is turning off. While the inductance may be small, just 5 nH would produce 5 V at a di/dt of 1000 A/µs which is not unusual. This inductance of 5 nH is just a few millimeters of wired connection (the FZ400R12KE4 has a stray package inductance of 16 nH). An appropriate negative drive ensures that the gate-emitter off-voltage is always zero or less.

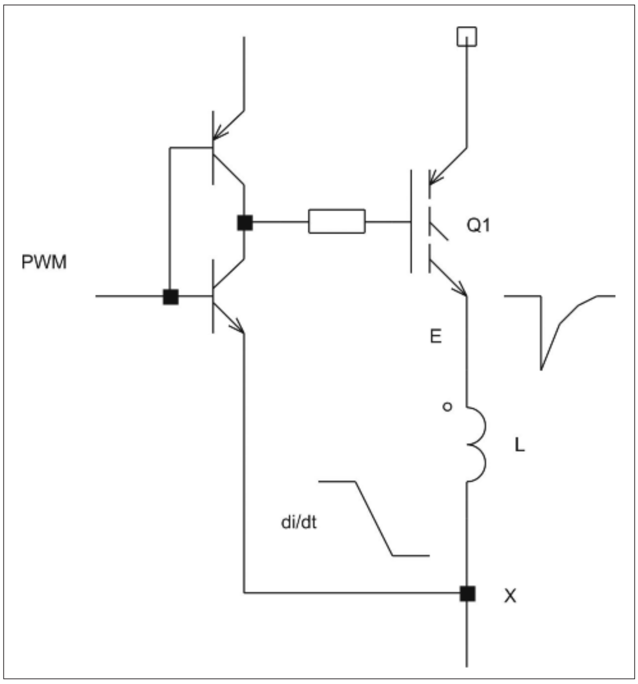

Figure 1: Switch-off with stray inductance L, negative di/dt produces a negative voltage on the emitter, opposing the turn-off voltage

A negative gate drive also helps to overcome the effect of collector-gate 'Miller' capacitance on device turn-off which works to inject current into the gate drive circuit. When an IGBT is driven off, the collector-gate voltage rises and current flows through the Miller capacitance of value C_m. d_{Vce}/d_t into the gate emitter capacitance C_{ge} and through the gate resistor to the driver circuit, see Figure 2. The resulting voltage V_{ge} on the gate can be sufficient to turn the IGBT on again with possible shoot-through and damage. Driving the gate to a negative voltage mitigates this effect.

A DC/DC converter with +15/-9V outputs conveniently provides the optimum voltages for the gate driver.

The gate of an IGBT must be charged and discharged through R_g in each switching cycle. If the IGBT data sheet provides a gate charge curve then the relationship is $P = Q_g$ x F xV_s where P is gate drive power, Q_g is data sheet charge for a chosen gate voltage swing, positive to negative, of value V_s.

If the data sheet does not provide a charge curve but just a Q_g value at specific gate voltages, the value of Q_g at other gate voltage swings can be approximated by multiplying by the ratio of the actual versus data sheet voltage swings. For example the FZ400R12KE4 has a Q_g value of 3.7 µC with ±15 V gate voltage swing (30 V total). For a swing of +15/-9 V (24 V total) gate charge approximates to $Q_g = 3.7e^{-6}$ x 24/30 ≈ 3 µC. At 10 kHz this requires gate drive power of $P_g = 3e^{-6}$ x $10e^{3}$ x 24 ≈ 0.72 W.

With derating and allowing for other incidental losses, a 2 W DC/DC converter would be suitable. In our example, with 24 V total gate voltage swing, the charge and discharge energy must be the same in each cycle, so the average charge and discharge current must be the same, at 30 mA given by P_g/V_s. The peak current I_{pk}, required to charge and discharge the gate

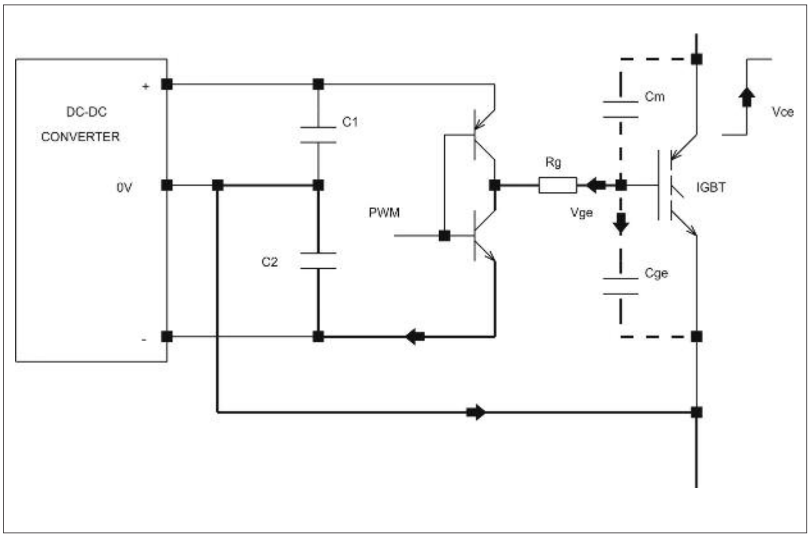

Figure 2: Current through 'Miller' capacitance C_m works to turn on the IGBT

is a function of V_s, gate resistance of the IGBT R_{int} and external resistance R_g. Thus $I_{pk} = V_s / (R_{int} + R_g)$.

The FZ400R12KE4 has $R_{int} = 1.9\ \Omega$ so with a typical external resistor of 2 Ω and a swing of 24 V, a peak current of over 6 A results. This peak current must be supplied by 'bulk' capacitors on the driver supply rails as the DC/DC converter is unlikely to have sufficient value of output capacitors to supply this current without significant 'droop'. Of course the gate driver itself must be rated for these peak current values as must the gate resistors. For our example, total gate drive energy E per cycle is given by $E = Q_g \times V_s = 72\ \mu J$.

The bulk capacitors on the +15 and -9 V rails supply this energy in proportion to their voltages so the +15 V rail supplies 45 μJ. If we assume that the bulk capacitor on the +15 V rail should not drop more than say 0.5 V each cycle then we can calculate minimum capacitance C by equating the energy supplied with the difference between the capacitor energies at its start and finish voltages, that is $45\ \mu J = \frac{1}{2} C (V_{init}^2 - V_{final}^2)$ and $C = (45e^{-6} \times 2)/(152 - 14.52) \approx 6.1\ \mu F$.

Although the -9 V rail supplies about a third of the energy, it requires the same capacitor value for 0.5 V drop as this is a larger percentage of the initial value.

Converter Considerations

It is advisable to place the IGBT driver and its DC/DC converter (Figure 3) as close as possible to the IGBT to minimize noise pick up and volt drops. This places the components in a potentially high temperature environment where reliability and lifetime reduces. DC/DC converters should be chosen with appropriate ratings and without internal components that suffer significantly with temperature such as electrolytic capacitors and opto-couplers. Data sheet MTTF values will typically be quoted at 25 or 40°C and should be extrapolated for actual operating temperatures.

The absolute values of gate drive voltages are not very critical as long as they are above the minimum, comfortably below breakdown levels and dissipation is acceptable. The DC/DC converters supplying the drive power therefore may be unregulated types if the input to the DC/DCs is nominally constant. Unlike most applications for DC/DCs however, the load is quite constant when the IGBT is switching at any duty cycle. Alternatively the load is close to zero when the IGBT is not switching. Simple DC/DCs often need a minimum load otherwise their output voltages can dramatically increase, possibly up to the gate breakdown level. This high voltage is stored on the positive bulk capacitor so that when the IGBT starts to switch, it could see a gate over-voltage until the level drops under normal load. A DC/DC should be chosen therefore that has clamped output voltages or zero minimum load requirements.

IGBTs should not be actively driven by PWM signals until the drive circuit voltage rails are at correct values. However, as gate drive DC/DCs are powered up or down, a transient condition might exist where IGBTs could be driven on, even with the PWM signal inactive, leading to shoot-through and damage. The DC/DC should therefore be well behaved with short and monotonic rise and fall times. A primary referenced on-off control can enable sequencing of power-up of the DC/DCs in a bridge reducing the risk of shoot-through.

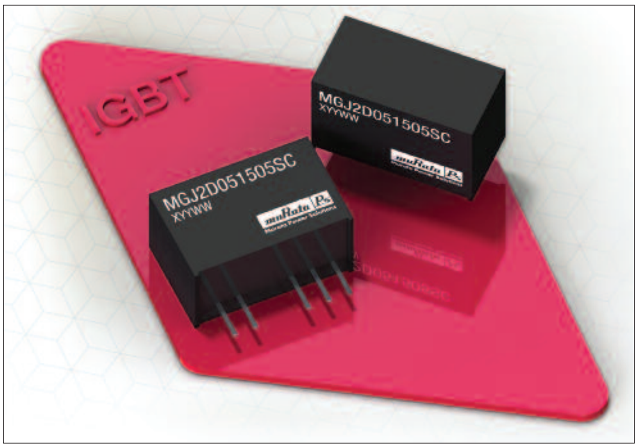

Figure 3. **Typical 2 W IGBT driver DC/DC converter, the MGJ2 from Murata Power Solutions**

Driving High-Speed Devices

DC/DCs for 'high side' IGBT drives see the switched 'DC-link' voltage across their barrier. This voltage can be kilovolts with very fast switching edges from 10 kV/μs upwards. Latest GaN devices may switch at 100 kV/μs or more. This high 'dV/dt' causes displacement current through the capacitance of the DC/DC isolation barrier of value $I = C \times dV/dt$.

So for just 20 pF and 10 kV/μs, 200 mA is induced. This current finds an indeterminate return route through the controller circuitry back to the bridge causing voltage spikes across connection resistances and inductances potentially disrupting operation of the controller and the DC/DC converter itself. Low coupling capacitance is therefore desirable, ideally less than 15 pF.

When the IGBT driver is powered by an isolated DC/DC converter, the barrier in the converter will be expected to withstand the switched voltage applied to the IGBTs which may be kilovolts at tens of kHz. Because the voltage is switched, the barrier will degrade over time faster than with just DC by electrochemical and partial discharge effects in the barrier material. The DC/DC converter must therefore have robust insulation and generous creepage and clearance distances. If the converter barrier also forms part of a safety isolation system, the relevant agency regulations apply for the level of isolation required (basic, supplementary, reinforced), operating voltage, pollution degree, over-voltage category and altitude.