AND9072/D

Effect of Gate-Emitter Voltage on Turn on Losses and Short Circuit Capability

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APPLICATION NOTE

Introduction

This application note describes some of the impacts of the gate-emitter voltage on the IGBT device performance. Unlike the MOSFETs and BJTs, the magnitude of the gate-emitter supply voltage of an IGBT has a more significant impact on the performance of the device. The magnitude of the gate-emitter voltage impacts the turn-on loss and short circuit survival capability of the devices.

Background

While both MOSFETs and IGBTs have certain similarities in terms of a gate terminal being used to switch the device, there are operational differences that need to be considered when driving the IGBTs. A typical MOSFET's switching behaviour is minimally impacted by the gate voltage levels beyond a certain level. As a result, it makes sense to restrict the gate voltage in MOSFET drive circuit so that the total gate charge (Q_G) value is minimized. However, in case of IGBTs, there are other considerations, so when transitioning from MOSFETs to IGBTS, these considerations may require a re-evaluation of optimum gate voltage level.

IGBT Turn-on Switching Loss Considerations

There are three major areas of consideration when selecting the V_{GE} value for an IGBT.

1. V_{CE} variation – Unlike a MOSFET that gets fully enhanced at relatively low gate voltage (in most MOSFET output characteristics, there is minimal gain once V_{GS} crosses 10 V), the output/saturation characteristics of the IGBTs show continuing dependence on the V_{GE} voltage. This is best illustrated in the attached Figure 1 from an IGBT datasheet. As shown in the curves, there is a significant gain to be had in the saturation voltage (V_{CE}), as the V_{GE} value is increased beyond 11 V for same collector current value. In fact, higher current is not supportable until V_{GE} is increased above 13 V. Given high current applications, even a 0.1 V improvement in V_{CE} translates into power savings of 1 W for every 10 A of collector current.

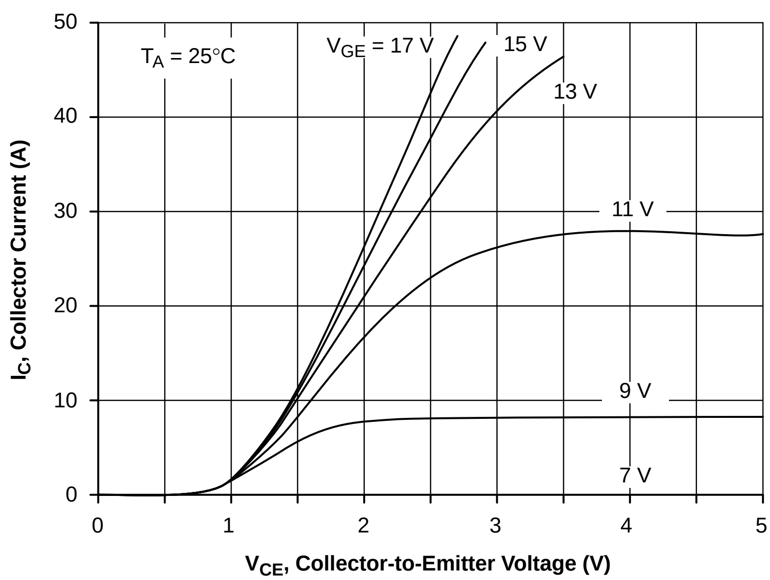

Figure 1. Output Characteristics of a 15 A, 600 V IGBT

2. Gate charge considerations – In order to fully turn-on the device in high voltage application, both MOSFET and the IGBT drivers must supply voltage beyond the plateau voltage that is needed to overcome the equivalent of the Miller effect in the device (providing the Q_{GD} and Q_{GC} charge at a constant voltage to the MOSFET and IGBT, respectively). The plateau voltage is shown in Figure 2. As shown here, the typical IGBT has a higher plateau voltage (near 10 V) than a typical MOSFET (near 5 V). There is also a higher variability in the IGBT plateau voltage as a function of collector current. As a result, it makes sense to set the IGBT V_{GE} value higher than the typical FET V_{GS} value. However, in both cases, increasing the gate voltage beyond the plateau voltage increases the value of total gate charge that has to be delivered every switching cycle. If we partition the gate-voltage vs. Q chart in three regions as shown in the figure, the first section is the Q_{GE} – from origin to the point the plateau region is reached. The next one is the Q_{GC} – which represents the plateau region and finally, the charge in the 3rd region is proportional to the actual value of V_{GE}. In this instance, every 2 V increase in V_{GE} value beyond the plateau voltage, leads to increase of about 10 nC in Q_G value. This increase leads to higher dissipation in the device as well as in the drive circuit due to the additional gate charge, but will also result in a lower V_{CE}. In that sense, it is advisable to keep the V_{GE} value always above the plateau voltage, but not too much higher than it.

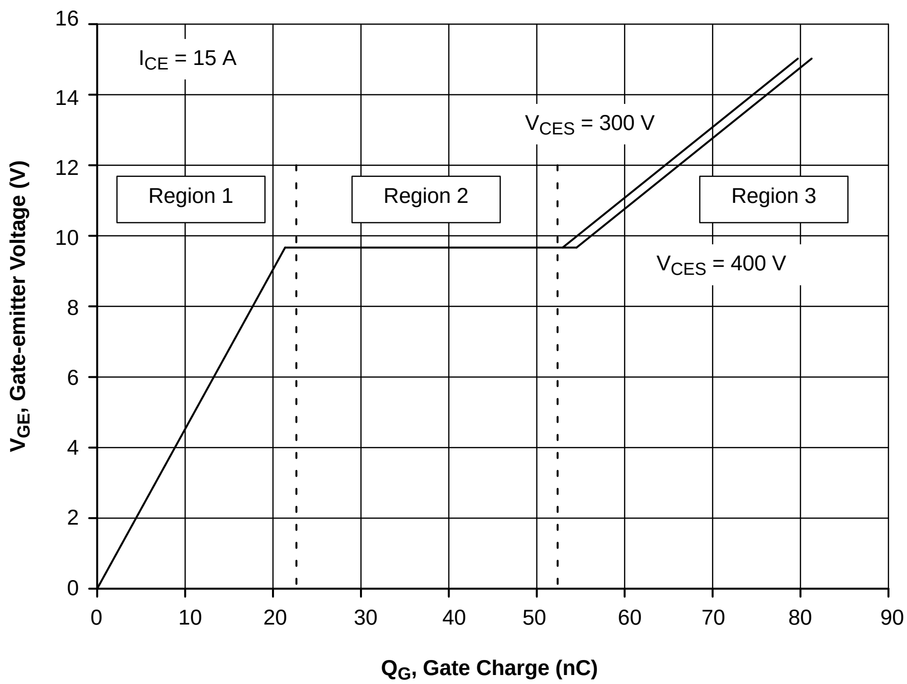

Figure 2. Gate Voltage vs. Gate Charge Characteristics (15 A, 600 V IGBT)

3. Transition time considerations – In addition to the factors described above, the turn-on time of the device is also determined by the V_{GE} value. With a given V_{GE} value, the available drive current is inversely proportional to the value of R_G. With a fixed R_G, an increase in V_{GE} results in a higher current and reduces the Q_{GE} section of the charge. This also results in shorter switching interval and significantly reduced turn-on energy – note that turn-on and turn-off energies in hard-switching applications are dominated by the collector current and voltage transitions. Many of the IC drivers are specified in terms of current drive capability, and hence increasing the V_{GE} value may have less impact in the applications where these drivers are used.

As shown in Figure 3, there is a dramatic drop in the turn-on energy, Eon, once the V_{GE} value goes above 12 V. However, there is not much difference in Eon for V_{GE} values between 15 V and 20 V. This applies for the full current range. As depicted in Figure 4, the variations in R_G also resulted in a significant variations in the Eon value. Based on these figures, it can be surmised that a high V_{GE} value (between 15 V and 18 V) and a low R_G value are the best combination for driving IGBTs.

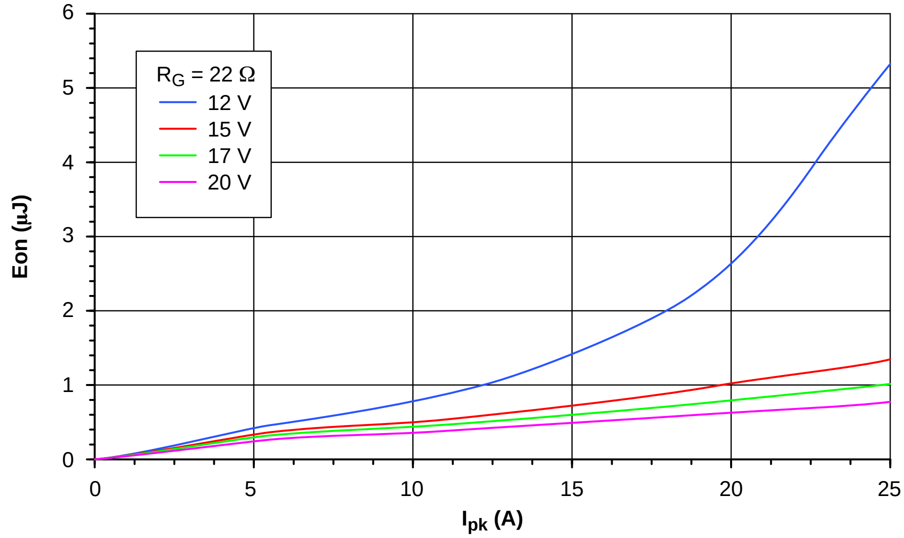

Figure 3. Turn-on Energy Characteristics (Fixed R_G and varying V_{GE})

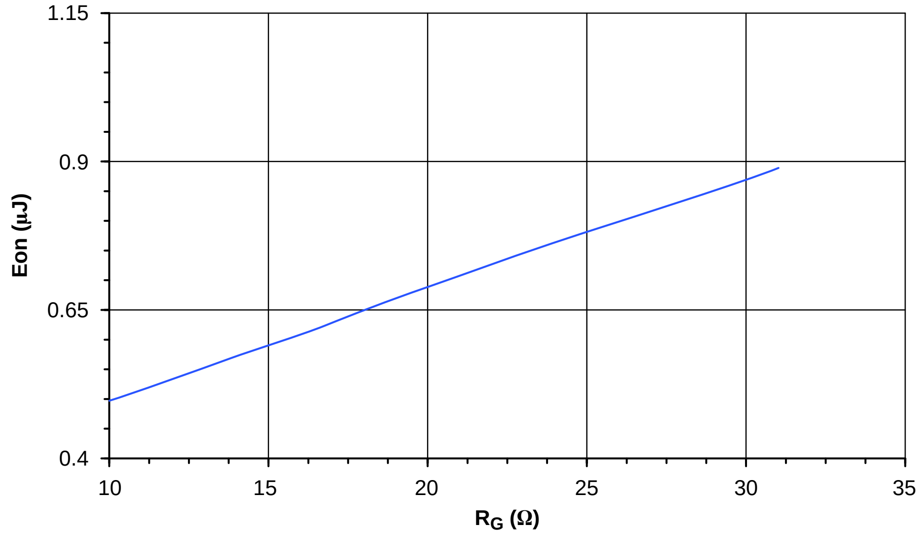

Figure 4. Turn-on Energy Characteristics (Fixed V_{GE} and varying R_G)

Based on the above three considerations, following key summaries can be drawn about the impact of V_{GE} value on IGBT switching performance:

- It is better to use higher drive voltage, V_{GE}, (around 15 V) for IGBTs compared to the FET drive circuits
- While higher voltage helps in many ways (saturation, transition time etc.), pushing it too high can increase the gate charge requirements.
- Some margin from absolute maximum values (±20 V, typically) must be maintained to prevent any transients on the drive voltage from damaging the IGBTs.

Short Circuit Fault Operation

A major concern in inverter and motor drive applications is the ability to survive a short circuit fault condition. During the short circuit fault, the device is exposed to the supply voltage across the device, while the gate potential is at full operating value (see Figure 5). Because of the high gain characteristic of the IGBTs, the collector current will rise to some undetermined value limited by the gate-emitter voltage. During this time the device will have a large amount of energy across the device, and if the energy is beyond the capability of the device it will be destroyed due to thermal breakdown. For non-rugged devices, the large current can cause parasitic NPN bipolar transistor to turn on and cause the device to latch, wherein the gate control will be lost.

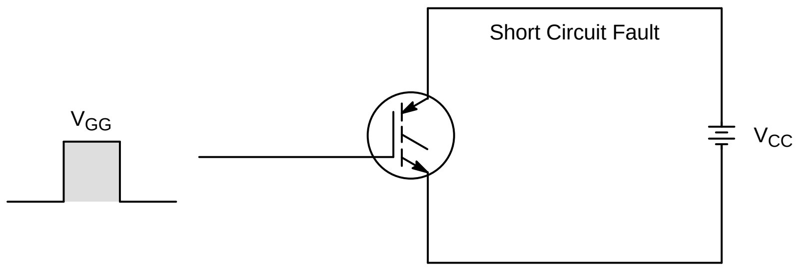

Figure 5. Equivalent Short Circuit Condition

Since an IGBT is less sensitive to second breakdown due to hot spot formulation compared to a BJT, it can survive a short circuit condition if the energy delivered to the device is maintained below some value that is tolerable to the device. An IGBT is typically specified with a guaranteed short circuit withstand time under given conditions (a typical value is 10 μs). It is expected that this withstand time allows an external circuitry to be activated and intervene to rectify the condition.

There are many different ways to protect the device from the short circuit condition for some duration. The most effective way to provide the short circuit survivability would be to inherently build current sensing capability into the device – however, that is not an option in most cases. Another method of increasing the short circuit survivability is to decrease the gate voltage when the short circuit across the device is observed. Figure 6 data shows the relationship between the gate voltage, short circuit current, and the short circuit survival time period. As shown in Figure 6, it is clear that the smaller gate voltage limits the current at lower value and increases the short circuit time duration. Thus, if more rugged performance and longer short circuit survivability is needed, it may make sense to trade-off some of the switching loss gain and reduce the V_{GE} voltage in the application.

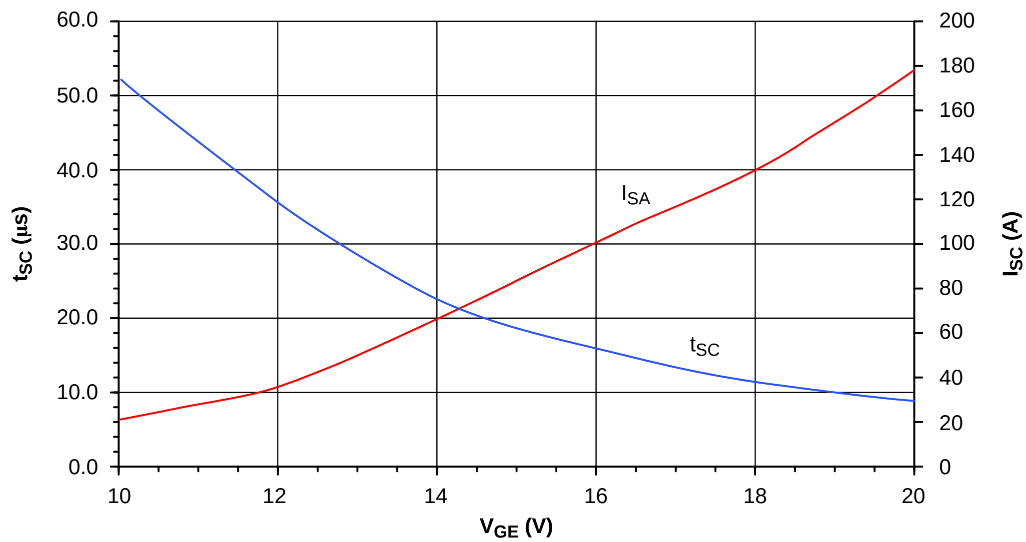

Figure 6. Short Circuit Response of IGBT

Summary

IGBTs are high current and high voltage devices that offer certain benefits compared to the MOSFETs. Because of their use in high power applications, both lifetime considerations (ruggedness) and efficiency (low losses) are important. As discussed in this section, the magnitude of the gate-emitter voltage can be optimized in order to reduce the turn-on loss of the device. But on the other hand, the designer needs to understand that the high gate-emitter voltage reduces the short circuit survivability of the device. Using these two relationships and taking into consideration specific application requirements, the designer can choose the best voltage value (and the best IGBT) which will meet the design requirements.

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