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www.Semikron.com/Application/DriverCalculation

IGBT Driver Calculation

This application note provides information on the determination of driver output performance for switching IGBTs. The information given in this application note contains tips only and does not constitute complete design rules; the information is not exhaustive. The responsibility for proper design remains with the user.

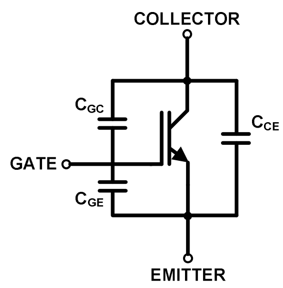
Introduction

One key component of every power electronic system is – besides the power modules themselves – the IGBT driver, which forms the vital interface between the power transistor and the controller. For this reason, the choice of driver and thus the calculation of the right driver output power are closely linked with the degree of reliability of a converter solution. Insufficient driver power or the wrong choice of driver may result in module and driver malfunction.

Gate Charge Curve

The switching behaviour (turn-on and turn-off) of an IGBT module is determined by its structural, internal capacitances (charges) and the internal and outer resistances. When calculating the output power requirements for an IGBT driver circuit, the key parameter is the gate charge. This gate charge is characterised by the equivalent input capacitances C_{GC} and C_{GE}.

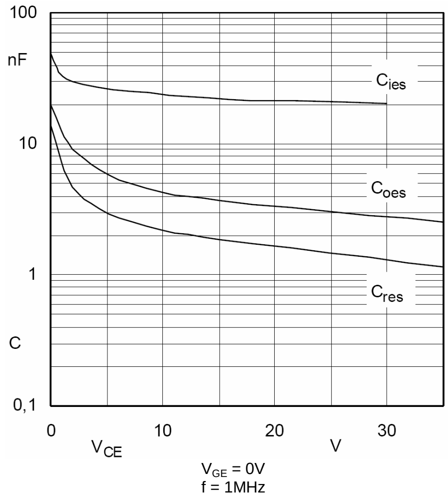
IGBT Capacitances



The following table explains the designation of the capacitances. In IGBT data sheets these capacitances are specified as voltage-dependent low-signal capacitances of IGBTs in the “off” state. The capacitances are independent of temperature, but dependent on the collector-emitter voltage, as shown in the following curve. This dependency is substantially higher at a very low collector-emitter voltage.

Parasitic and Low-Signal Capacitances	
Capacitances	**Designation**
C_{GE}	Gate-emitter capacitance
C_{CE}	Collector-emitter capacitance
C_{GC}	Gate-collector capacitance (Miller capacitance)
Low-Signal Capacitances	**Designation**
$C_{ies} = C_{GE} + C_{GC}$	Input capacitance
$C_{res} = C_{GC}$	Reverse transfer capacitance
$C_{oes} = C_{GC} + C_{CE}$	Output capacitance

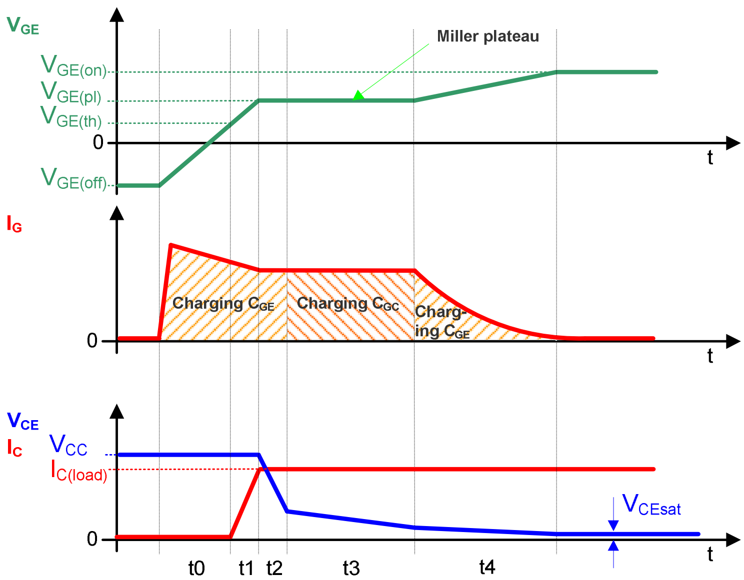
C_{ies}, C_{oes}, C_{res} = f(V_{CE})



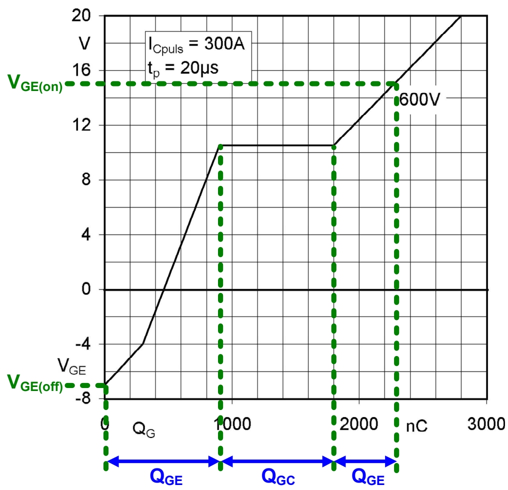
The following table shows simplified the gate charge waveforms V_{GE}= f(t), I_G=f(t), V_{CE}=f(t), and I_C=f(t) during turn-on of the IGBT. The turn-on process can be divided into three stages. These are charging of the gate-emitter capacitance, charging of the gate-collector capacitance and charging of the gate-emitter capacitance until full IGBT saturation.

To calculate the switching behaviour and the driver, the input capacitances may only be applied to a certain extent. A more practical way of determining the driver output power is to use the gate charge characteristic given in the IGBT data sheets. This characteristic shows the gate-emitter voltage V_{GE} over the gate charge Q_G. The gate charge increases in line with the current rating of IGBT modules. The gate charge is also dependent on the DC-Link voltage, albeit to a lesser extent. At higher operation voltages the gate charge increases due to the larger influence of the Miller capacitance. In most applications this effect is negligible.

Simplified Gate Charge Waveforms



Gate Charge Characteristic



t0 switching interval: The gate current I_G charges the input capacitance C_{GE} and the gate-emitter voltage V_{GE} rises to $V_{GE(th)}$. Depending on the gate resistor, several amperes may be running in this state. As V_{GE} is still below $V_{GE(th)}$, no collector current flows during this period and V_{CE} is maintained at V_{CC} level.

t1 switching interval: As soon as V_{GE} passes $V_{GE(th)}$, the IGBT turn-on process starts. I_C begins to increase to reach the full load current $I_{C(load)}$, which is valid for an ideal free-wheeling diode (shown in the simplified waveform). For a real free-wheeling diode, I_C exceeds $I_{C(load)}$. This is because a reverse recovery current, which flows in reverse direction, is added to $I_{C(load)}$. Since the free-wheeling diode is still conducting current at the beginning of section t2, the collector-emitter voltage V_{CE} will not drop. V_{GE} reaches the plateau voltage $V_{GE(pl)}$.

t2 switching interval: V_{GE} maintains $V_{GE(pl)}$. When the free-wheeling diode is turned-off, V_{CE} starts to drop rapidly and dv_{CE}/dt is high.

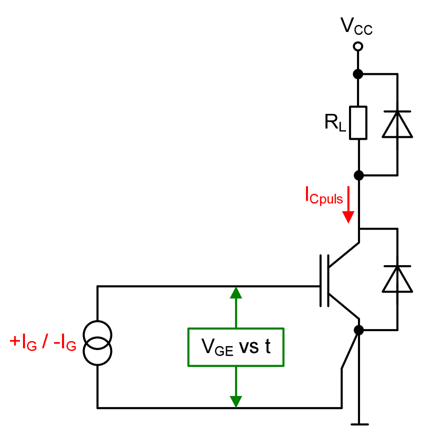
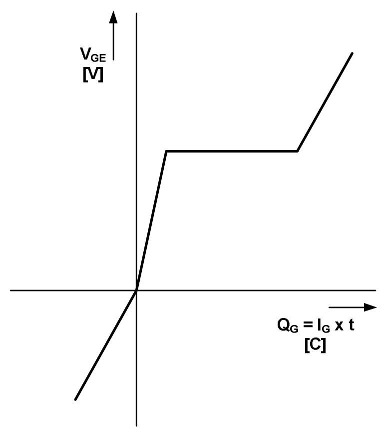
t3 switching interval: While V_{CE} is decreasing to reach on-state value V_{CEsat}, the Miller capacitance C_{GC} increases as the voltage decreases and is charged by I_G. V_{GE} still remains on a plateau, which is $V_{GE(pl)}$ level.

t4 switching interval: At the beginning of section t4, the IGBT is fully turned-on. The charge conducted to C_{GE} induces an exponential increase in V_{GE} up to the gate control voltage $V_{GE(on)}$. I_G ends with an exponential fade out and V_{CE} reaches V_{CEsat} level.

During turn-off the processes described are running in reverse direction. The charge has to be removed from the gate.

Measuring the Gate Charge

A simplified test circuit that can be used to measure the gate charge is shown in the following table. The gate is supplied by a constant gate current. Furthermore, a pulse constant collector current is applied. The constant gate current causes the measured waveform $V_{GE} = f(t)$ to be equivalent to $V_{GE} = f(Q_G)$ due to $Q_G = I_G \times t$.
The document IEC 60747-9, Ed.2: Semiconductor Devices – Discrete Devices – Part 9: Insulated-Gate Bipolar Transistors (IGBTs) describes the gate charge test method.

<table>
<tr><th>Basis Test Circuit for Gate Charge Measurement</th><th>Waveform $V_{GE} = f(t) \Leftrightarrow V_{GE} = f(Q_G)$</th></tr>
<tr><td>
</td><td>
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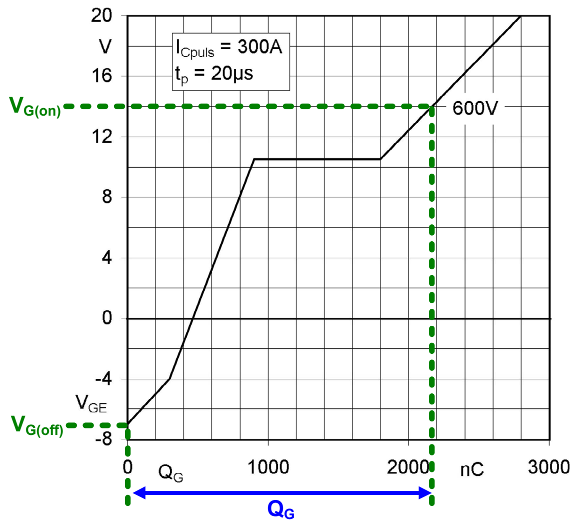
</table>

Determining the Gate Charge

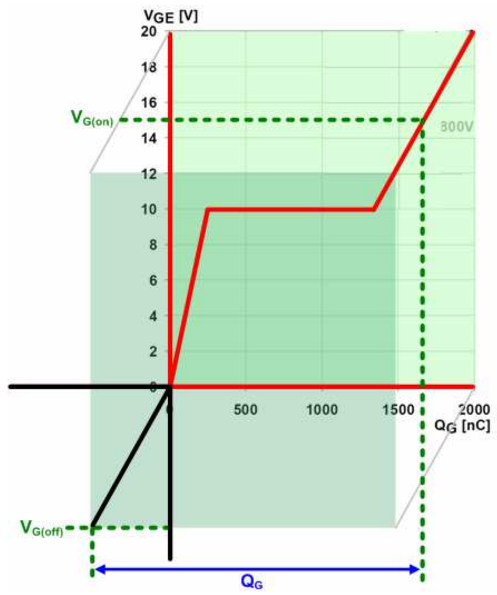
The gate charge per pulse needed to drive the IGBT can be determined using the gate charge characteristic diagram, which shows gate-emitter voltage over gate charge. The total gate charge can be read out by taking into account the amplitude of the applied gate voltage, i.e. from turn-on gate voltage $V_{G(on)}$ to turn-off gate voltage $V_{G(off)}$. The SEMIKRON IGBT data sheet shows the gate charge curve in the positive and negative quadrant.

If the gate charge curve is given in the positive quadrant only, the gate charge amplitude can be read out by extrapolation, as shown in the following table. The bright green represents the area of a diagram given in the IGBT data sheet. A parallel adjustment of the bright green area along the gate charge curve into the negative quadrant up to $V_{G(off)}$ allows for the amplitude of the gate charge to be determined.

Gate Charge Characteristic (e.g. SKM400GB126D)



Extrapolation Method



Another method for determining the gate charge uses the input capacitance C_{ies} and a special factor instead of the gate charge curve. The value for C_{ies} is given in the IGBT data sheet.

The necessary gate charge or the charging energy per pulse must be available at the right time. This can only be achieved by using low-impedance, low-inductance output capacitors at the driver output stage. The size of the capacitors is indicated by the calculated value Q_G. The gate charge is the basic parameter used to determine driver output power and gate current.

Gate Charge Calculation with C_{ies} Method

The gate charge can be expressed as

$$Q_G = C_G \times (V_{G(on)} - V_{G(off)})$$

where $C_G = k_C \times C_{ies}$

The gate capacitance factor k_c can be roughly calculated as

$$k_C = \frac{Q_{G(ds)}}{C_{ies} \times (V_{G(on)} - V_{G(off)})}$$

where $Q_{G(ds)}$ is the value specified in the IGBT data sheet, and $V_{G(on)}$ as well as $V_{G(off)}$ are the gate voltages applied to $Q_{G(ds)}$.

Thus, the alternative gate charge calculation is as follows:

$$Q_G = k_C \times C_{ies} \times (V_{G(on)} - V_{G(off)})$$

Please note:

This method is not entirely accurate and should be only used if no gate charge curve is available.

Driver Output Power

The individual power of each internal supply needed to drive the IGBT can be found as a function of the intended switching frequency and the energy which has to be used to charge and discharge the IGBT.

Calculation of Driver Output Power per Channel

Power can be expressed as

$$P_{GD(out)} = E \times f_{sw}$$

Substituting $E = Q_G \times (V_{G(on)} - V_{G(off)})$,

the driver output power per channel is:

$$P_{GD(out)} = Q_G \times (V_{G(on)} - V_{G(off)}) \times f_{sw}$$

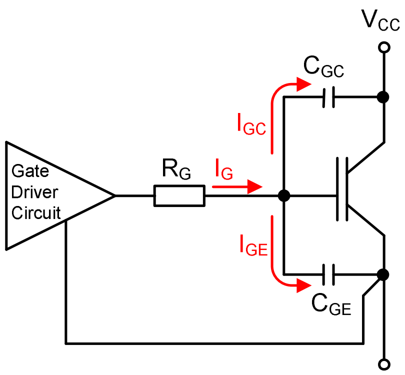
Rough calculation of driver power using the C_{ies} method:

$$P_{GD(out)} = k_C \times C_{ies} \times (V_{G(on)} - V_{G(off)})^2 \times f_{sw}$$

Gate Current

One of the key requirements for IGBT driver circuits is that enough current be supplied to charge and discharge the input capacitances of the IGBT and thus to switch the IGBT on and off. This gate current can be calculated using the equations for IGBT input capacitance charging. The gate current calculated is the minimum average output current I_{outAVG} of the driver output stage per channel.

IGBT Capacitances



Calculation of Gate Current

Charge can be calculated as follows:

$$Q_G = \int i dt$$

With $Q_{GE} = i_{GE} \times t_{sw}$, $Q_{GC} = i_{GC} \times t_{sw}$

the total gate charge is:

$$Q_G = Q_{GE} + Q_{GC} = (i_{GE} + i_{GC}) \times t_{sw}$$

Substituting $t = \frac{1}{f_{sw}}$

the average gate current is:

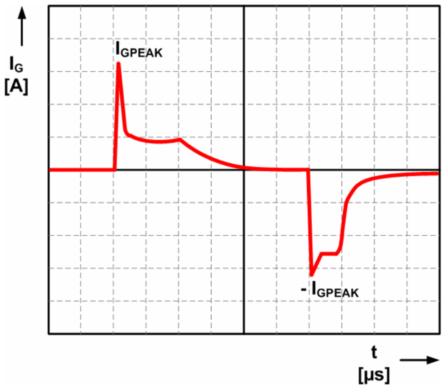
$$I_G = I_{GE} + I_{GC} = Q_G \times f_{sw}$$

Roughly calculation of average gate current by using the C_{ies} method::

$$I_G = k_C \times C_{ies} \times (V_{G(on)} - V_{G(off)}) \times f_{sw}$$

Peak Gate Current

The IGBT switching time is controlled by charging and discharging the gate of the IGBT. If the gate peak current is increased, the turn-on and turn-off time will be shorter and the switching losses reduced. This obviously has an impact on other switching parameters such as overvoltage stress, which have to be watched. The gate charge currents can be controlled by the gate resistors $R_{G(on)}$ and $R_{G(off)}$. The theoretical peak current value I_{GPEAK} can be calculated using the equation below. The IGBT module's internal gate resistor $R_{G(int)}$ must be taken into account when calculating the peak gate current. In practice, stray inductance reduces the peak value below the possible theoretical value.

<table>
<tr><th>Peak Gate Current</th><th>Calculation</th></tr>
<tr><td>
</td><td>The peak gate current can be calculated as follows:

$$I_{GPEAK} = \frac{V_{G(on)} - V_{G(off)}}{R_G + R_{G(int)}}$$</td></tr>
</table>

In the data sheet of an IGBT driver, a maximum peak current is given, as are the minimum values for the gate resistors. If both these maximum and minimum ratings are exceeded, the driver output may be destroyed as a result.

Selection Suitable IGBT Driver

When selecting the suitable IGBT driver for the individual application, the following details have to be considered:

- The driver must be able to provide the necessary gate current (output current / output power). The maximum average output current of the driver must be higher than the calculated value.
- The maximum peak gate current of the driver must be equal to or higher than maximum calculated peak gate current.
- The output capacitors of the driver must be able to deliver the gate charge needed to charge and discharge the gate of the IGBT. In the data sheet of SEMIKRON drivers the maximum charge per pulse is given. This value must be duly considered when selecting a suitable driver.

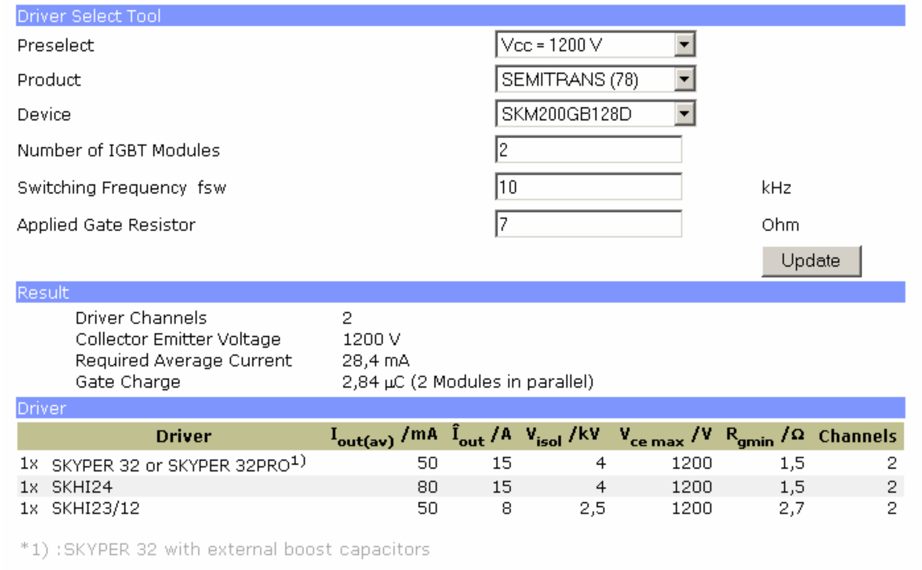
Other parameters worth mentioning in the context of IGBT driver selection are insulation voltage and dv/dt capability.

DriverSel – The Easy IGBT Driver Calculation Method

DriverSel facilitates IGBT driver calculation and the selection of a suitable driver, regardless of the application. This software tool takes into consideration the aforementioned characteristics and equations, and calculates suitable IGBT drivers on the basis of the IGBT module selected, the number of paralleled modules, gate resistor, switching frequency and collector-emitter voltage. This tool can be used for driver calculation and selection for any brand and IGBT package, as well as to calculate the necessary gate charge and average current.

Link: DrivelSel is a free software tool and is available on the SEMIKRON homepage at http://semisel.semikron.com/DriverSelectTool.asp.

DriverSel Screenshot



Symbols and Terms used

Letter Symbol	Term
C_{CE}	Collector-emitter capacitance
C_G	Effective gate capacitance
C_{GC}	Gate-collector capacitance
C_{GE}	Gate-emitter capacitance
C_{ies}	Input capacitance IGBT
C_{oes}	Output capacitance IGBT
C_{res}	Reverse transfer capacitance IGBT
dv_{CE}/dt	Rate of rise and fall of collector-emitter voltage
E	Electrical energy
f_{sw}	Switching frequency
I_C	Collector current
I_{Cpuls}	Pulse constant collector current
I_G	Gate current
I_{GM}	Peak gate current
I_{outAVG}	Average output current of the driver
k_C	Gate capacitance factor
$P_{GD(out)}$	Driver output power
Q_G	Gate charge
Q_{GC}	Gate-collector charge
Q_{GE}	Gate-emitter charge
R_G	Gate resistor
$R_{G(int)}$	IGBT module internal gate resistor

$R_{G(off)}$	Turn-off gate resistor
$R_{G(on)}$	Turn-on gate resistor
t	Time
t_{sw}	Switching time
V_{CC}	Collector-emitter supply voltage
V_{CE}	Collector-emitter voltage
V_{CEsat}	Collector-emitter saturation voltage
V_G	Gate voltage (output driver)
$V_{G(off)}$	Turn-off gate voltage (output driver)
$V_{G(on)}$	Turn-on gate voltage (output driver)
V_{GE}	Gate-emitter voltage
$V_{GE(pl)}$	Plateau gate-emitter during switching
$V_{GE(th)}$	Gate-emitter threshold voltage

References

[1] www.SEMIKRON.com

[2] Application Manual Power Modules, SEMIKRON International

[3] M. Hermwille, "Plug and Play IGBT Driver Cores for Converters", Power Electronics Europe Issue 2, pp. 10-12, 2006

[4] M. Hermwille, "Gate Resistor – Principle and Application", Application Note AN-7003, SEMIKRON

[5] P. Bhosale, M. Hermwille, "Connection of Gate Drivers to IGBT and Controller", Application Note AN-7002, SEMIKRON

[6] IEC 60747-9, Ed.2: Semiconductor Devices – Discrete Devices – Part 9: Insulated-Gate Bipolar Transistors (IGBTs)

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