The use of gate resistors to control IGBT switching
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Power semiconductors are used for controlling, conditioning and switching purposes in applications that demand higher voltages and currents.

The switching behaviour of power semiconductors is controlled by the gate capacitance recharge. This gate capacitance recharge usually is controlled via a gate resistor. By using a typical positive control voltage \( V_{\text{G(on)}} \) of +15 V the IGBT is turned-on and turned-off at a negative output voltage \( V_{\text{G(off)}} \) of typically -5...-8...-15V. The dynamic IGBT performance can be adjusted by the value of the gate resistor which influences the IGBT switching time, switching losses and a variety of other parameters from electromagnetic interference (EMI) to voltage and current changes. The gate resistor therefore has to be selected and optimised very carefully in accordance with the individual application parameters.

The switching behaviour setting of each IGBT is affected by the external resistor \( R_G \). As the input capacitance of an IGBT, which varies during switching time, has to be charged and discharged, the gate resistor will dictate what time is needed to do this by limiting the magnitude of the gate current \( I_G \) pulses during turn-on and turn-off (Fig. 1). Due to the increase in the gate peak current, which is affected by reducing the turn-on and turn-off gate resistor values \( R_{G(on)} \) and \( R_{G(off)} \), the turn-on and turn-off time will be shorter and the switching losses will be reduced. What needs to be considered when reducing the value of the gate resistor is the current behaviour \( \text{di/dt} \) generated when high currents are switched too fast. Stray inductance \( L_s \) present in the circuit produces a high voltage spike \( V_{\text{strain}} \) on the IGBT. This effect can be observed in the waveform shown for IGBT turn-off in Fig. 2. The shaded areas show the relative value of the switching losses. The transient voltage spike on top of the collector-emitter voltage may destroy the IGBT, especially in short-circuit turn-off operation with a high \( \text{di/dt} \). \( V_{\text{strain}} \) can be reduced by increasing the value of the gate resistor. Thus, the risk of IGBT destruction due to overvoltage can be eliminated. Fast turn-on and turn-off leads to higher \( \text{dv/dt} \) and \( \text{di/dt} \) values respectively. Thus, more electromagnetic emissions (EMI) are produced and can bring about circuitry malfunction in the application. Table 1 shows the tendencies of changes in gate resistor values in IGBT.

The switching behaviour of the free-wheeling diode protecting the IGBT is also affected by the gate resistor and limits the minimum value of the gate resistance. This means that the turn-on switching speed of the IGBT can only be increased up to a level compatible with the reverse recovery behaviour of the free-wheeling diode that is used. A decrease in the gate resistor increases not only the overvoltage stress on the IGBT, but also on the free-wheeling diodes caused by the increased \( \text{di/dt} \) in IGBT modules. The usage of specially designed, optimised control axial lifetime diodes with soft recovery behaviour allows for a low peak reverse current and hence a lower turn-on current on the IGBTs in bridge circuits.

Table 1: Rating/characteristics.

<table>
<thead>
<tr>
<th>Rating/ Characteristics</th>
<th>( R_G )</th>
<th>( R_{G(on)} )</th>
<th>( R_{G(off)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turn-on peak current</td>
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<tr>
<td>Turn-off peak current</td>
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<tr>
<td>( \text{dv/dt} )</td>
<td></td>
<td></td>
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<tr>
<td>( \text{di/dt} )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage spike</td>
<td></td>
<td></td>
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<tr>
<td>EMI noise</td>
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</table>

The driver output stage of a gate drive circuit is typically designed with two MOSFETs in totem pole configuration as can be seen in Fig. 3. Both gates of the MOSFETs are driven by the same signal. When the signal is high, the N-channel MOSFET is on and when the signal is low, the P-channel MOSFET is on. The result is a push-pull output configuration with two transistors. The MOSFET output stage is available with one or two outputs. Depending on whether the output...
stage has one or two outputs, different solutions for symmetrical or asymmetrical gate control with one or two gate resistors (on, off) can be realised.

**Gate resistor dimensioning**

A gate resistor must demonstrate optimum switching behaviour with regard to low switching losses, no IGBT module oscillation, low diode peak reverse recovery current and maximum \( \frac{dv}{dt} \) limitation. Typically in applications, IGBT modules with a large current rating will be driven with smaller gate resistors; similarly, small IGBT modules will require larger gate resistors i.e. the value given in the IGBT data sheet has to be optimised for each design. IGBT data sheets specify a value for the gate resistor. The optimum value however will be somewhere between the value indicated and roughly twice this value. The gate resistor value specified in the IGBT data sheet is the minimum value; twice the rated nominal current can be safely switched off under the conditions specified. In practice, the gate resistor value in the IGBT data sheet cannot always be achieved due to differences between the test circuitry and the individual application parameters. The rough value mentioned (i.e. twice the data sheet value) may be taken as a starting point for optimisation to reduce the gate resistor value accordingly. The only way to ascertain the final optimum value is to test and measure the final system. It is important to minimise parasitic inductance in applications. This is necessary to keep the turn-off overvoltage at the IGBT within the limits specified in the IGBT data sheet, particularly in short-circuit conditions. The gate resistance determines the gate peak current \( I_{GM} \). Increasing the gate peak current will reduce the turn-on and turn-off time as well as the switching losses. The maximum value for the gate peak current and the minimum value for the gate resistor, respectively, are determined by the performance of the driver output stage.

**Design, layout and troubleshooting**

The gate resistor must meet certain performance requirements and have certain features in order to be able to withstand the substantial load that occurs in an application. Due to the substantial load on the gate resistors, the use of resistors in parallel is advisable. This would produce a redundancy enabling from temporary operation with higher switching losses should one gate resistor be damaged. Choosing the wrong gate resistors might cause problems and unwanted effects. If the selected gate resistor value is too high, major switching losses will occur. The gate resistor then has to be reduced, bearing in mind the switching performance of the whole application. A too high gate resistance value also might cause the IGBT to operate for a long time in linear mode during switching and finally results in gate oscillation. In case however the power dissipation as well as peak power capability of the resistor is not sufficient or a non-surge-proof resistor is in use, this will result in an overheated or even burned gate resistor. During operation, the gate resistor has to withstand a continuous flow of pulses. Therefore, the gate resistor has to have a certain peak power capability. EMI noises also might result from using a very small gate resistor as this leads to higher \( \frac{dv}{dt} \) or \( \frac{di}{dt} \) values.

A too high inductance in the application (DC-link) or a small turn-off gate resistor will lead to a higher \( \frac{di}{dt} \) and cause an excessive voltage spike at the IGBT. In consequence the inductance should be minimised or the turn-off gate resistor should be increased. To reduce voltage spike in the event of a short-circuit, a soft turn-off circuit that turns off the IGBT more slowly may be used. If the wiring between the gate resistor and the IGBT module is too long, it will lead to higher inductance in the gate-emitter path and, together with the input capacitance of the IGBT, will form a resonant LC circuit that gives rise to an oscillation. This can be damped simply by shorter wiring or by using a gate resistor that is larger than the minimum gate resistor \( R_{G\text{min}} \geq 2\sqrt{L_{\text{wire}}/C_{\text{ies}}} \).

**Additional reading**

[1]  www.semikron.com

**Contact**

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**IGBT Turn-off**

Fig. 2: IGBT turn-off.

**Connection** \( R_{G(on)} \), \( R_{G(off)} \)

Fig. 3: Connection \( R_{G(on)}/R_{G(off)} \)