PCIM Asia 2024, 28 – 30 August 2024, Shenzhen, China DOI:10.30420/566414100

High-voltage gate driver IC technology with integrated DESAT diode

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Abstract

Desaturation protection [1][2] is a very popular solution for short circuit protection in inverter applications. The desaturation detection circuit requires an external, high-voltage, fast recovery diode. This increases the size and cost of the PCB. Infineon offers a high-voltage gate driver IC technology [3] that integrates the desaturation-protection circuit and the high-voltage, fast-recovery, desaturation-detection diode monolithically to reduce the size of the PCB space and system costs.

1 Introduction

In a short circuit condition, the current flowing through the inverter increases rapidly and may exceed the maximum current rating of the power devices. This can cause the power devices to overheat and fail. This in turn can damage the inverter and potentially create a safety hazard. Short circuit protection is essential in an inverter to prevent equipment damage and ensure the safety of people and equipment. It is a mandatory requirement for many safety standards and it is crucial to include it in the design of any inverter application. The short circuit protection mechanism in an inverter is designed to detect a short circuit condition and immediately limit the current flow to protect the power devices. The protection circuit typically consists of a current sensor, a comparator, and a control circuit. The current sensor monitors the current flowing through the inverter, and the comparator compares the current with a predefined threshold level. If the current exceeds the threshold level, the control circuit triggers the protection mechanism, which shuts off the power devices.

This paper describes five different short circuit conditions, the short circuit protection circuits, and a new high-voltage gate driver IC technology (Infineon's Silicon-on-Isolator (SOI) technology). Using this technology, the high-voltage, fast-recovery, desaturation sense diode can be integrated into the high-voltage gate driver IC.

2 Short circuit

During real life operation of a motor inverter, the most common type of failure encountered by the power switch (e.g., IGBT) is a short circuit. When an IGBT experiences a short circuit, the collector-emitter voltage, V_{CE}, rises rapidly. It causes the IGBT to exit the saturation region and enter the active region. The short circuit current becomes three to five times the rated current in a very short time and the excessive current can burn out the IGBT device. Figure 1 shows the output characteristics of the IGBT. It describes the corresponding relationship between the I_C and V_{CE} when V_{GE} is fixed. After a short circuit fault occurs, the IGBT enters the active region that consumes a large amount of power and may damage the device. Therefore, it is essential to design a short circuit protection circuit for the IGBT.

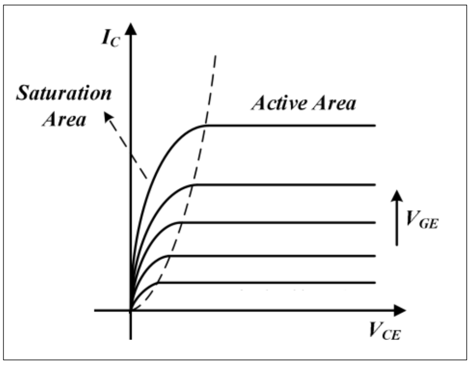

Fig. 1. Output characteristic curve of an IGBT

Figures 2 to 6 show five different short circuit conditions of a 3-phase inverter with current sensing in a negative DC BUS.

- Figure 2 shows a phase-to-phase short: In this case, the U-phase is short to V-phase, Q1 and Q4, or Q2 and Q3 are short-circuited when they turn on at the same time
- Figure 3 shows a phase-to-Com short: In this case, the V-phase is short to Com. Q3 is short-circuited when it turns on
- Figure 4 shows a phase-to-DC BUS- short: In this case, the V-phase is short to DC BUS-, Q3 is short-circuited when it turns on
- Figure 5 shows a phase-to-DC BUS+ short: In this case, the V-phase is short to DC BUS+, Q4 is short-circuited when it turns on
- Figure 6 shows a half-bridge short-through: In this case, the U-phase is short-through when Q1 and Q2 turn on at the same time

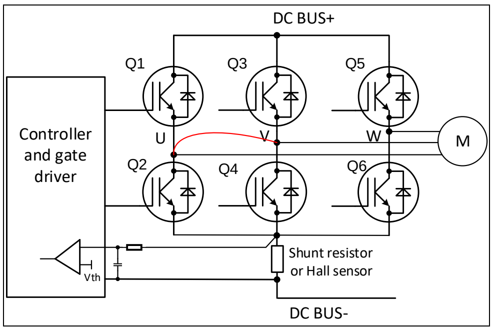

Fig. 2. Phase-to-phase short

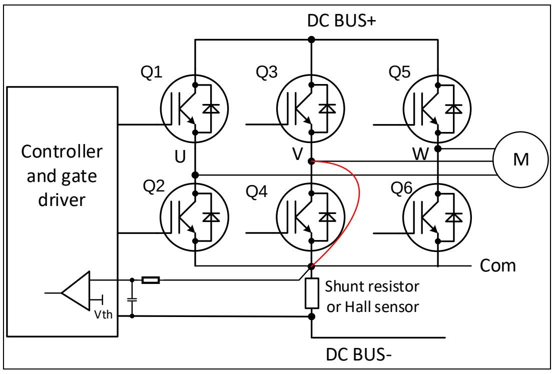

Fig. 3. Phase-to-Com short

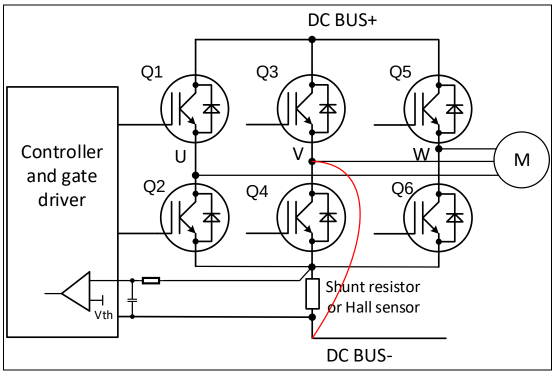

Fig. 4. Phase-to-DC BUS- short

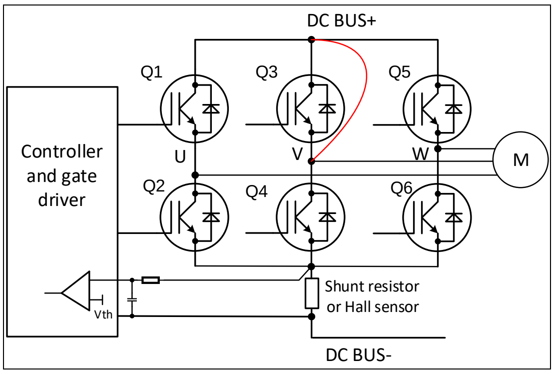

Fig. 5. Phase-to-DC BUS+ short

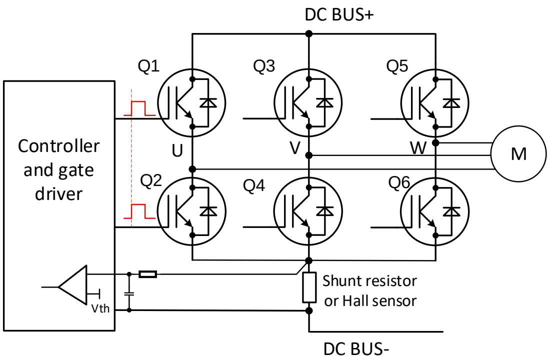

Fig. 6. Half-bridge short-through

3 Short circuit protection

3.1 Shunt resistor or Hall sensor protection

The shunt resistor [4] or Hall sensor (see Figure. 7) are popularly used in the inverter leg or the negative DC BUS to sense shoot-through faults. Fast-acting trip circuitry in the controller or gate drivers must shut down the IGBTs on time to prevent the short-circuit withstand time from being exceeded. The main disadvantage of this method is that additional measurement devices (e.g., shunt resistor or Hall sensor) need to be included along with addition of any associated circuitry. It increases the power loss. This method can protect from all the four short circuit conditions mentioned earlier, except the phase-to-DC BUS- short, because the short circuit current bypasses the current-sensing device.

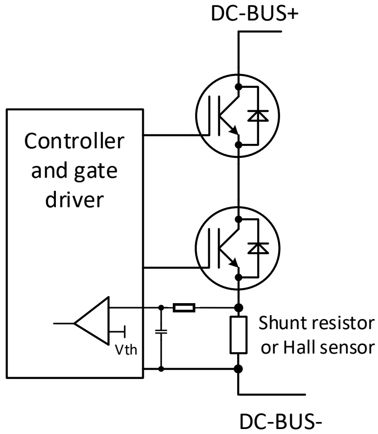

Fig.7. Shunt resistor or Hall sensor protection

3.2 DESAT protection

Desaturation detection utilizes the IGBT itself as the component to measure current. A DESAT diode (see Fig. 8) ensures that the IGBT collector-emitter voltage (V_{CE}) is only monitored by the detection circuit during on-time. During a normal operation, the collector-emitter voltage is very low (typically 1.5 V to 3.5 V) during on-time. However, if a short circuit event occurs the IGBT collector current rises to a level that drives the IGBT out of the saturated region and into the linear region of operation. This results in a rapid increase in the collector-emitter voltage. The above-normal voltage level can be used to indicate the existence of a short circuit. The desaturation threshold levels are typically in the 7 V to 9 V range. On detecting an IGBT overcurrent (V_{CE} is over the threshold), the circuit shuts down the IGBT within its short circuit withstand time. DESAT protection can protect from all the previously mentioned short circuit conditions. The main disadvantage of this method is that it requires a high-voltage, fast-recovery DESAT diode, along with any associated circuitry.

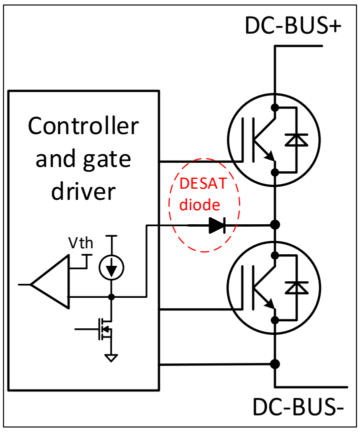

Fig. 8. DESAT protection

4 High-voltage gate driver IC technology

4.1 Silicon-on-insulator (SOI) technology

The silicon-on-insulator (SOI) is an advanced, integrated circuit technology that includes a buried oxide layer in the silicon substrate. Figure 9 shows the layout of a half-bridge gate driver and a cross-section based on Infineon's SOI technology). This structure provides an effective way of insulating the active area from the silicon substrate in the vertical direction. Together with local oxidation (LOCOS), all active devices are isolated from each other so there is no parasitic bipolar transistor structure and no latch-up effect. The technology can integrate with high-voltage, fast-recovery desaturation sense diode and the bootstrap diode monolithically.

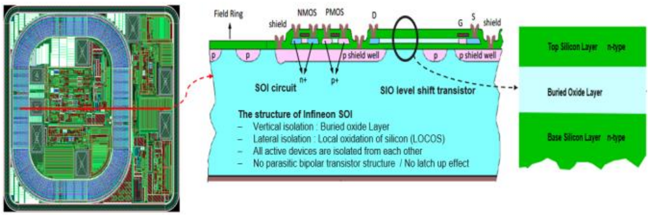

Fig. 9. Layout of a half-bridge gate driver and a cross-section based on Infineon's SOI technology

4.2 Gate driver integrated with DESAT protection circuitry and DESAT diode

The requirements of a DESAT diode are:

- A low current diode (< 20 mA). It is sufficient because the forward bias current flowing is normally less than 1 mA
- A diode reverse breakdown voltage equivalent to the V_{CE} breakdown voltage of the IGBT
- A small junction capacitance (< 5 pF at 600 V). This is necessary to prevent a DESAT malfunction
- A low reverse recovery time (t_{rr} < 100 ns) and energy to prevent switching loss

Figure 10 shows a high-voltage, half-bridge gate driver monolithically integrated with a high-voltage fast recovery ($t_{rr} \approx 50$ ns) DESAT diode and a DESAT protection circuitry based on Infineon's SOI gate drive technology.

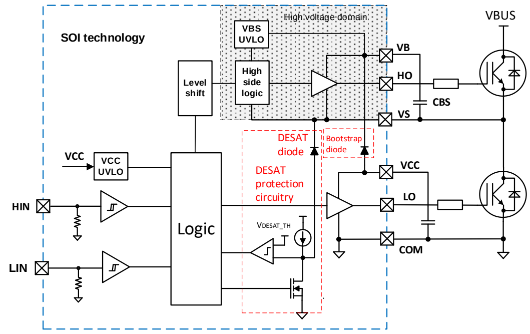

Fig. 10. Gate driver integrated with DESAT protection and DESAT diode

5 Conclusion

Desaturation protection can protect from all the five different short circuit conditions in inverter applications. The desaturation detection circuit requires a high-voltage, fast recovery diode that increases costs and the PCB size. Infineon offers a high-voltage gate driver IC technology that can integrate the desaturation protection circuit that includes a high-voltage, fast-recovery desaturation-detection diode, and a high-voltage, fast-recovery bootstrap diode monolithically. It reduces the PCB size and also the total system costs.

6 References

[1] SS Ahmad, KNV Prasad, and G Narayanan, "Improved Short-Circuit Protection Scheme with Fast Fault Detection for SiC MOSFET", 2022 IEEE Energy Conversion Congress and Exposition (ECCE)

[2] 1ED020I12-F2 (1200 V single high-side gate driver IC with DESAT protection) datasheet, Infineon Technologies, Germany

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