Influence of Short Circuit conditions on IGBT Short circuit current in motor drives

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ABSTRACT
Protecting the IGBTs against short circuit conditions is a critical aspect of the Industrial motor drive design. The SC (short circuit) conditions can occur in a variety of ways in an industrial environment. The SC applied across the motor drive terminals result in a different fault current profile than a SC that happens at the motor terminals or between inter winding coils. The packaging parameters such as number of wire bond contacts, thermal impedance of the package also have significant impact on the short circuit current profile and the robustness of the system.

The voltage spike suppression methods and gate driver response to the over current shut down conditions influence the robustness of the system.

This paper studies the influence of the inductance of the short circuit on the saturation current of the IGBT and its effects on the device robustness. The paper also briefly discusses the transient suppression methods and soft shut down methods for the gate drive circuit to improve the robustness.

INTRODUCTION
Reliability is a paramount requirement for industrial systems. Understanding the short circuit currents under various conditions is essential to design effective protection circuits and to design reliable packages and systems. In a typical motor drive system, the short circuit can happen in a variety of conditions like phase to phase, phase to DC bus –ve & +ve terminals, at the motor terminals.

The amount of inductance in the short circuit determines the current profile and the power dissipation in the IGBT. If the inductance is low, the di/dt at turn on is high and the IGBT enters de-saturation phase quickly and the junction heats up quickly. If the inductance is high, the di/dt at turn on is low and it delays the IGBT saturation. During the time current is ramping up, the voltage across the IGBT, the power dissipation and the junction temperature rise are low. The IGBT can survive the short circuit much longer under these conditions. The larger inductance also causes a larger voltage spike at turn off. Care must be taken to limit the voltage spike under conditions to be below the breakdown voltage of the IGBT.

If the short circuit is applied to an IGBT that is already conducting, the dv/dt resulting from the rapid de-saturation of the IGBT would boost the gate voltage of the IGBT and results in higher peak SC current (Fig 5 & 6). The increased peak current would increase the power dissipation and could cause IGBT failures.

Use of RC & RCD snubber circuits can help reduce the voltage spike applied on the IGBT at turn off. The draw backs of these snubber circuits are increased cost, size and losses in the circuit. The effective way of protecting the IGBTs under over current conditions is to use soft turn-off methods. Selectively slowing the IGBT turn-off under over current conditions could reduce the transient voltage spike applied on the IGBT and improve the reliability of the system. This method does not affect the efficiency of the system under normal operating conditions.

Experimental Results of different SC conditions:

The short circuit current of the IGBT depends on the forward transconductance (G_{FE}) of the IGBT. G_{FE} of the IGBT has a negative temperature co-efficient. As the IGBT junction heats up during the short circuit conditions, the G_{FE} reduces and hence the SC current of the IGBT reduces (Fig 1 & 2). If the short circuit of the IGBT occurs through a long cable, the inductance of the cable reduces the di/dt of the short circuit current and the voltage across the IGBT until the IGBT enters the de-saturation mode. The same phenomenon can occur if the package, PCB and the interconnect inductance of the system is large. As a result of the reduced di/dt and V_{CE} during the SC condition reduces the power dissipation in the IGBT and the junction temperature.

At lower temperatures, the G_{FE} is higher and results in larger SC current (Fig 3). If the short circuit of the IGBT occurs across the terminals of the drive, the low inductance of the short circuit results in high di/dt of the short circuit current and the IGBT enters the de-saturation mode quickly. As a result of the high di/dt and V_{CE} during the SC condition increases the power dissipation in the IGBT and the junction temperature. At high temperatures, the G_{FE} is lower and results in smaller SC current (Fig 4).

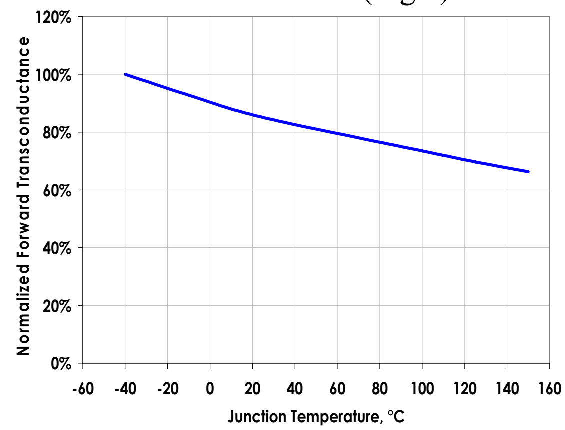

Fig 1 IGBT forward Transconductance vs. Junction temperature

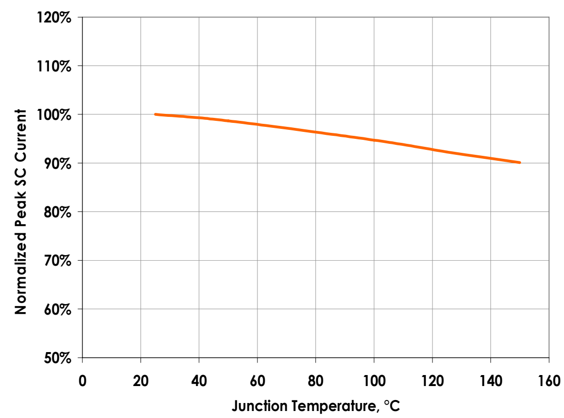

Fig 2 IGBT Peak SC Current vs. T_J

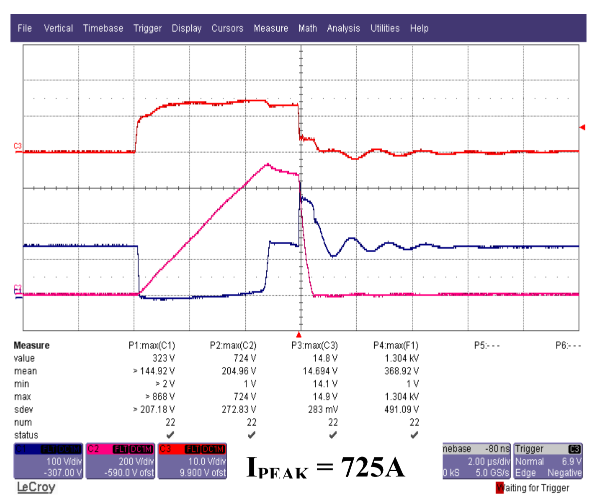

Fig 3 SC through High Inductance

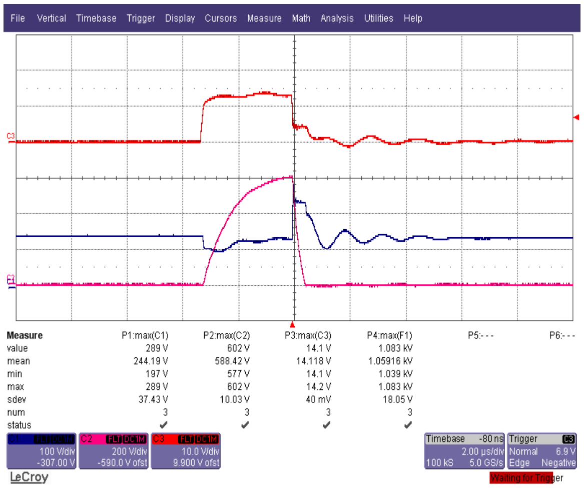

Fig 4 SC through low Inductance

Applying a negative V_{GE} at turn-off will result in faster turn-off and higher di/dt. Higher di/dt results in larger voltage spike across the IGBT at turn-off (Fig 7 & 8). Higher the $-V_{GE}$ at turn-off, higher will be the di/dt at turn-off and the resulting V_{SPIKE}. Care must be taken in the design to ensure sufficient voltage margin is maintained to avoid driving the IGBT in to dynamic break down conditions.

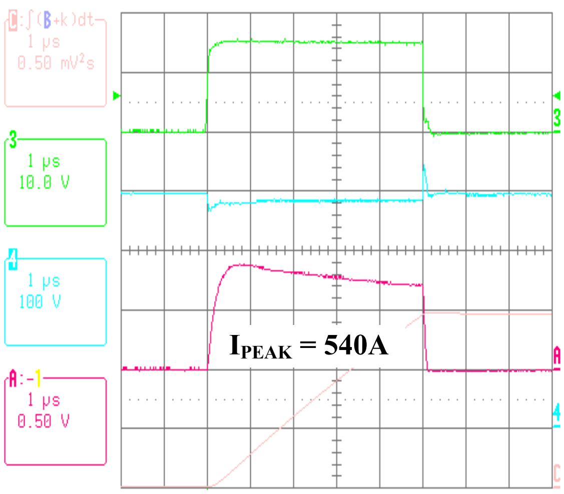

Fig 5 IGBT turns ON into a SC

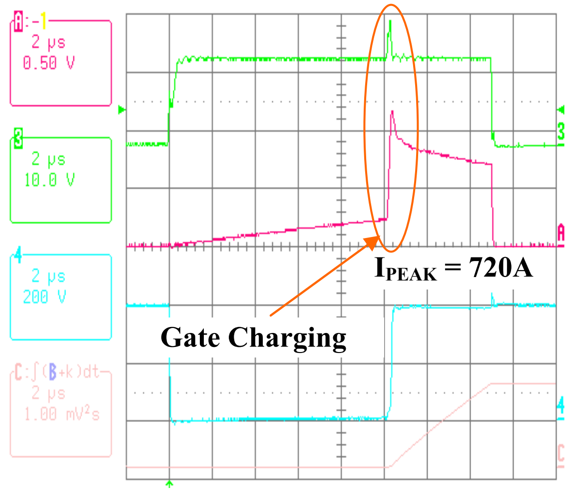

Fig 6 SC is applied to an IGBT already ON

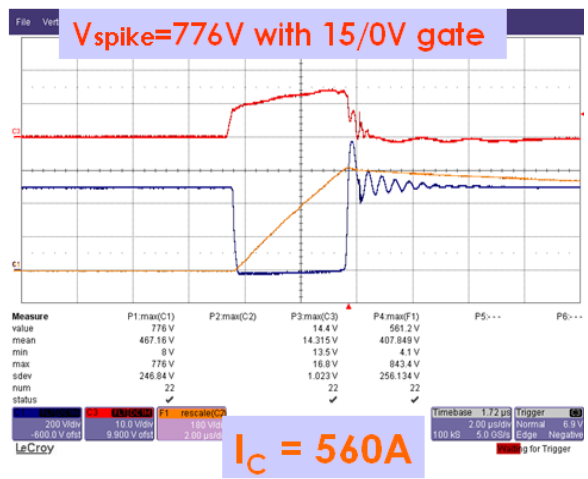

Fig 7 V_{SPIKE} with V_{GE} = 0V at turn-OFF

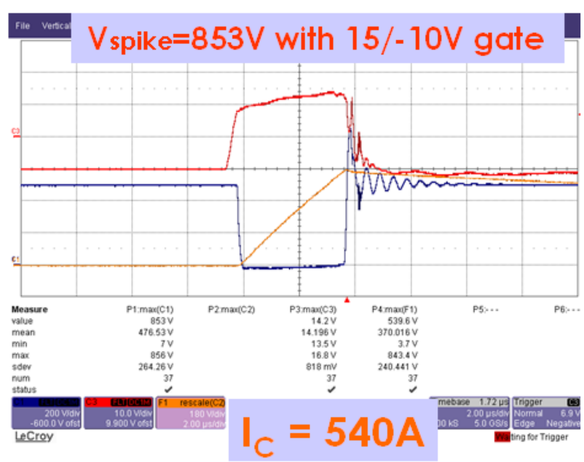

Fig 8 V_{SPIKE} with V_{GE} = -10V at turn-OFF

Methods to improve the robustness in SC conditions:

Snubber Circuits: Use of RC & RCD snubber circuits can reduce the V_{SPIKE} on the IGBTs at turn-off and improve the reliability of the system (Fig 9 & 10). The snubber circuit operates by slowing down the switching di/dt of the IGBT to reduce the peak voltage transient. Snubber circuits increase the system cost, size and the losses considerably and are not a very useful method for systems sensitive to these parameters.

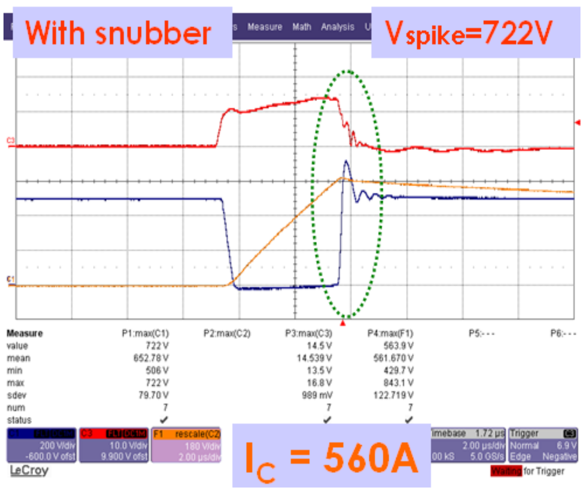

Fig 9 V_{SPIKE} with RC snubber circuit

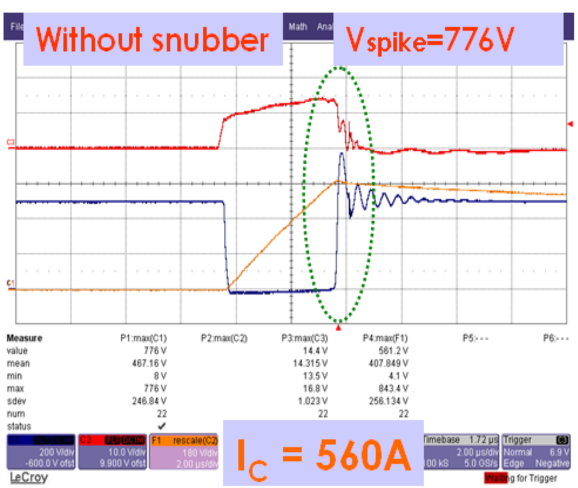

Fig 10 V_{SPIKE} without RC snubber circuit

Soft shutdown methods: Use of soft shut down conditions could reduce the V_{SPIKE} across the IGBT and improve the reliability of the system in SC conditions (Fig 11 & 12). The soft shut down methods are very effective compared to the snubber circuits and these methods are preferred because; slow turn-off is employed only during over current turn-off situations and hence does not affect the performance of the system under normal operating conditions. This feature can be achieved without much cost burden on the system and also without increasing the size of the system. Soft switching increases the system reliability in critical applications and is an effective way to achieve cost, performance and reliability trade-off.

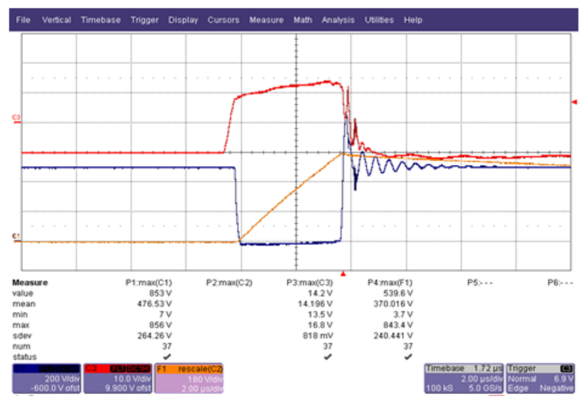

Fig 11 V_{SPIKE} without soft shut down

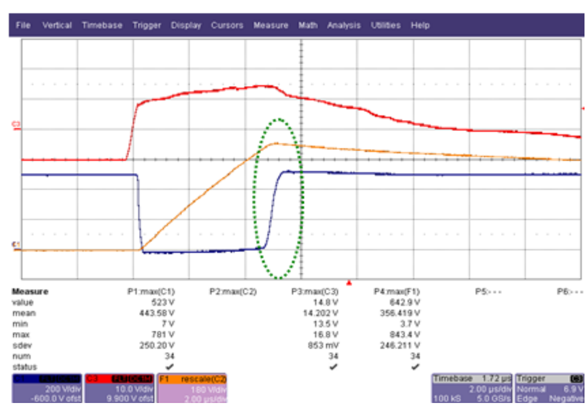

Fig 12 V_{SPIKE} with soft shut down

CONCLUSIONS

The short circuit current of an IGBT varies depending on the fault conditions. Thorough understanding of the SC behavior of the IGBT under various conditions is essential to design effective protection circuits, package (wire bonds, trace widths, terminal sizing) and system design (PCB traces, inter connect cables, fuses etc). Use of transient suppression methods and soft shut down methods help improve the reliability of the system.

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