

Triple Pulse Tester - Efficient Power Loss Characterization of Power Modules

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Keywords

<<Characterization>>, <<Switching losses>>, <<Conduction losses>>, <<Efficiency>>.

Abstract

In this paper the triple pulse testing method and circuit for power loss characterization of power modules is introduced. The proposed test platform is able to accurately characterize both the switching and conduction losses of power modules in a single automated process. A configuration of a half bridge is tested by making a sweep of the junction temperature, dc-link voltage, and current for a given gate drive and dc-bus setup. Test results are presented for a 1700 V 1400 A IGBT power module.

Introduction

Power loss data of a power device or power module is given in datasheets (if available) as typical values. Therefore, the characteristics from one production lot to another can be different. Generally the conditions for the power loss data given in datasheets are limited to a single dc-link voltage, and two or three temperatures, for a single gate resistance and usually with limited or no information on the dc-bus stray inductance. In case of linearization of power loss curves, usually done in a simulation software, the calculation of turn-ON losses can be with very high errors due to the voltage non-linearity of the losses. For accurate power loss characterization of a power module, the measurement of the specific sample must be executed. Moreover, if the assessment of changes according to the lifetime of a power module is desired the measurement is necessary.

Conduction losses are typically measured using a curve tracer [1]. For a set point of the baseplate temperature, the I-V curve is obtained by a sweep of the voltage applied to the device and measurement of the current.

Switching losses are typically measured in a double pulse tester [2], [3], [4]. The change of the inductor connection must be done in a double pulse tester to be able to measure the characteristic of a specific transistor/diode. To measure the switching losses at different temperatures the sweep of the temperature must be done, similarly like in the case of measuring conduction losses in a curve tracer.

Results that the whole process of measuring the losses of a power module is time consuming because of the need of mounting the device under test (DUT) in two different instruments. A sweep of the temperature must be done for each instrument resulting in further waste of energy required for heating. For accurate temperature set-points, the temperature control loop is very slow - making the whole process very slow.

This paper proposes a new test platform for characterizing both the switching and conduction losses of a power electronic module. The measurement is performed in the same circuit, with a single temperature loop making the characterization process faster and user friendly. Test result data is presented for a half-bridge 1700 V 1400 A IGBT module, for a sweep in discrete steps of the temperature, current and dc-link voltage.

Switching loss measurement (Double Pulse Test)

Switching loss measurements are typically measured with a double pulse test. The required test setup for measuring the losses in the low side devices can be seen in Figure 1. The principle measurement is shown in Figure 2, for measuring the turn-ON and turn-OFF energy losses of the low side transistor. Applying the same pulse pattern for the high side transistor, the reverse recovery can be measured in the low side diode when the high side transistor is turned ON at high current in the second pulse.

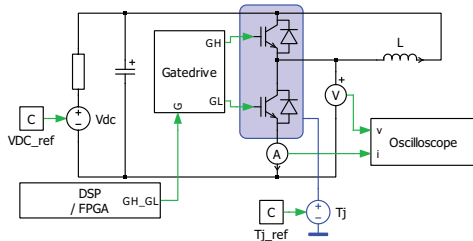


Figure 1: Double pulse circuit

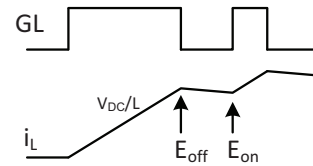


Figure 2: Double pulse principle

To calculate the power loss, and integrate the power to get the energy loss a synchronous measurement of the voltage across the device, and the current flowing through the device is required. The synchronization of the probes is critical to accurately measure the power loss, as well as appropriate bandwidth and parasitics of the used probes. Usually an oscilloscope is used to sample the voltage and current measurements, where the resolution and bandwidth must be high enough as well.

Switching and Conduction Loss Measurement (Triple Pulse Test)

The required circuit and principle of the triple pulse test are shown in Figure 3 and 4. Compared to the double pulse test circuit from Figure 1, an auxiliary half-bridge converter leg is necessary to be able to connect the inductor to both the positive and negative terminals of the DC-link capacitor. To be able to measure the conduction losses of the power module under test, while being able also to switch the device ON and OFF for measurement of the switching losses, a collector-emitter voltage measurement circuit must be used. An example of such a circuit of the collector-emitter voltage measurement introduced in [5] could be used. The on-stage voltage drop is measured only when the transistor or the diode is turned ON, while the circuit is able to block the high voltage when the transistor or diode is turned OFF.

The measuring principle of the triple pulse test is shown in Figure 4. The first two pulses are standard as in the double pulse test, while the third pulse is used to measure the conduction losses. By default, the

switching losses are measured on the low side for the low side transistor and low side diode. To be able to measure the switching losses on the high side as well, measurement probes and oscilloscope can be installed in the high side as well with the proper isolation and voltage potential reference.

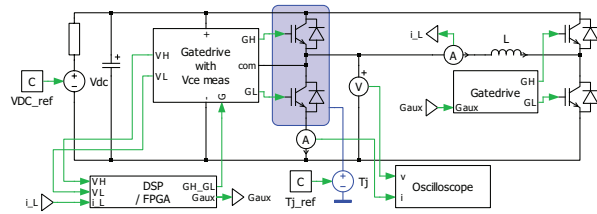


Figure 3: Triple pulse circuit

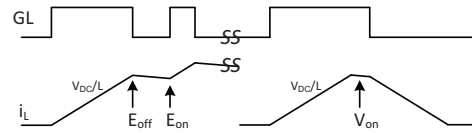


Figure 4: Triple pulse principle

The conduction losses of the DUT can be measured for each transistor and diode. The voltage is measured by the Vce measurement circuit synchronously with the current measurement of the load inductor. The voltage and current measurement data is acquired by the control platform which can be a digital signal processor (DSP) or field programmable gate array (FPGA). It can be seen that the current and voltage measured when the device is turned on is measured in a very low $\frac{di}{dt}$ condition, resulting in a clean and accurate measurement. The length of the 0 V vector applied during the conduction losses measurement is to be adjusted according to the bandwidth of the Vce measurement circuit. The resolution of the conduction loss measurement is given by the quality of the integrated analog to digital (ADC) converter from the Vce measurement circuit.

Test Results

Triple pulse test setup

A triple pulse tester for 1700 V IGBT modules was realized according to the circuit from Figure 3, and is presented as a rack mount system in Figure 5. The software components required to run the prototype automatic are presented in Figure 6. A high level control program is implemented in LabVIEW to control the temperature of the power module, setup current and voltage references, and collect the conduction loss data. A DSP is used to generate the gate signals, and measure the conduction losses. A 12 bit oscilloscope is used to measure the switching losses, via a 500 MHz voltage probe and 200 MHz current probe.



Figure 5: Triple pulse test setup

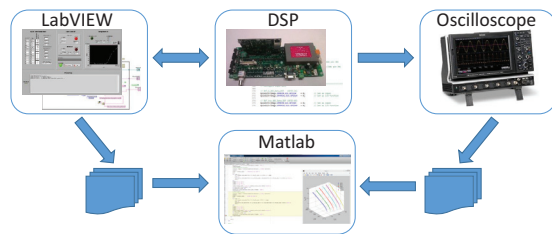


Figure 6: Triple pulse tester software components

The control of the system consists of a three loops: temperature, voltage and current. The outer and the slowest loop is the temperature, controlled using a heat-plate with a uniform temperature distribution and accuracy of 0.1 °C. For each temperature set-point, the DC-link capacitor bus is charged to the set-point given by the voltage range for test and the voltage resolution. Finally for each voltage set-point a current loop is generating pulses to measure both the conduction and switching losses.

Conduction loss measurement

The designed on-state measurement system has a 14 bit ADC, resulting a voltage resolution below 1 mV. The temperature during test was controlled from 25 °C to 150 °C in steps of 25 °C. The raw conduction loss data for two devices from the four devices under test are shown in Figure 7 and 8, for a 1700V 1400A IGBT power module. A sweep of the current was done from 0 A to 2800 A (twice the rated current). The gate voltage on the transistors is fixed by the gatedrive to around 15 V, giving the power loss in the transistor as seen in Figure 7.

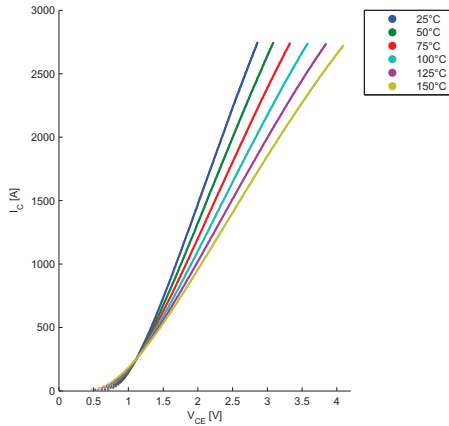


Figure 7: Conduction loss - high side transistor

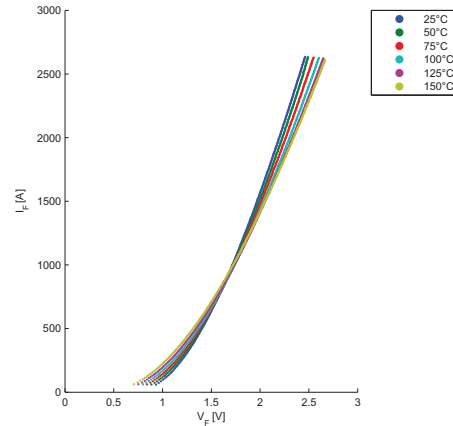


Figure 8: Conduction loss - low side diode

Switching loss measurement

Switching losses are measured in the same range as for the conduction losses, up to twice the module rated current which is the maximum current where a converter can operate safely (with repetitive pulse). The measurements that will be next presented are taken for the low side transistor and diode.

The switching energy integration limits from are considered according to [5]. The transistor turn-ON energy is integrated from when the collector current goes beyond 10% of the nominal value up to when the voltage falls down to 2% of the nominal value. Transistor turn-OFF energy is integrated from when the voltage goes beyond 10% of the nominal value up to when the current falls below 2% from the nominal value. Reverse recovery losses are integrated from when the reverse voltage goes beyond 10% of the nominal value up to when the reverse recovery current falls below 2% of the maximum reverse current.

Typical waveforms for the voltage, current, power and energy are given in Figures 9 and 10 for a switching behavior at 150 °C. The busbar stray inductance was around 12 nH, detected automatically at the turn-ON transient. The rise time and current slope are detected also according to [5], namely from 10% to 90% of the nominal value. DC-link voltage was around 1100 V and current around 1000 A. The turn-OFF transient can be seen in Figure 10, where an 10% over-voltage is noticed due to the equivalent stray inductance in the DC-link busbar. The voltage rise time is detected similarly as for the turn-ON current. Repeating the test for different currents, voltages and temperature, an energy loss model can be created. The extraction of the energy losses from the test based model can be seen in Figures 11 to 16. For a constant parameter, temperature in this case, the energy loss for different currents and voltages can be seen. It can be seen the big difference in switching loss at turn-ON and turn-OFF, with the turn-ON losses accounting for around 2 to 3 times more compared with the turn-OFF losses. Especially at high voltage, the dissipated energy approaches 4 J.

Keeping the voltage constant, the temperature dependency power loss can be seen in Figures 17 to 19. It can be noticed the nonlinear behavior of the reverse recovery losses in the diode at currents approaching the repetitive pulse limit.

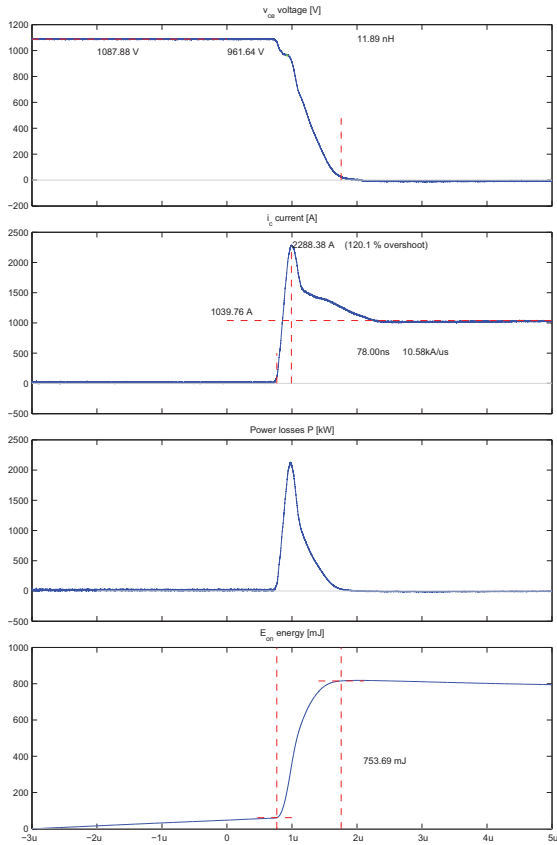


Figure 9: Turn-ON waveforms at 150 °C

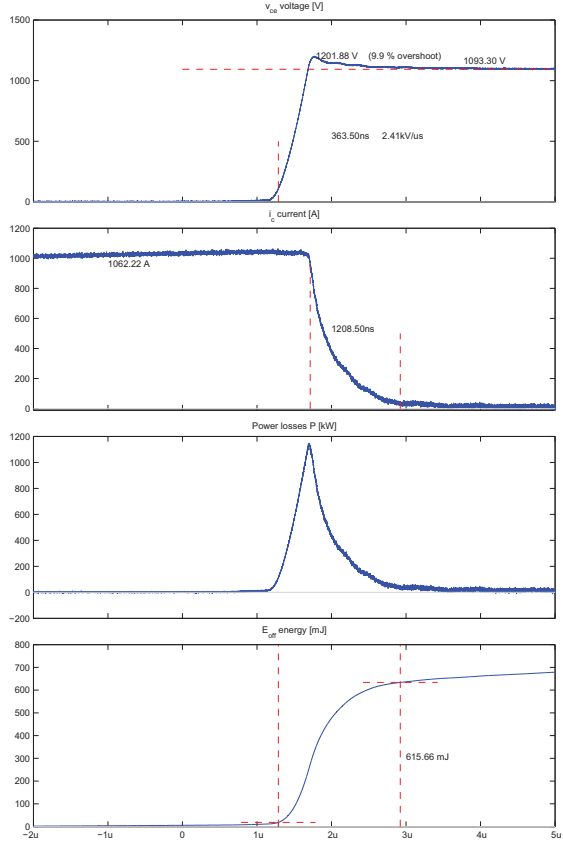


Figure 10: Turn-OFF waveforms at 150 °C

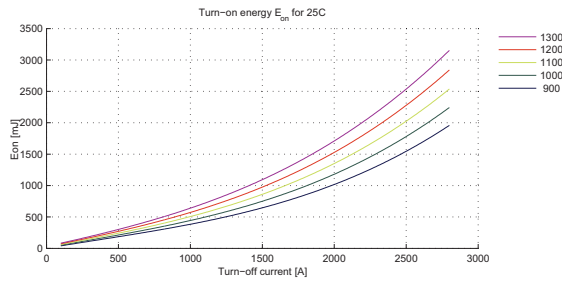


Figure 11: Turn-ON losses at 25 °C

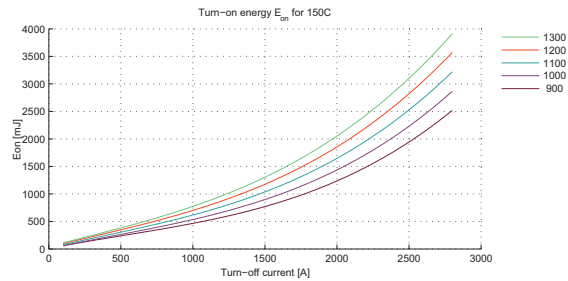


Figure 12: Turn-ON losses at 150 °C

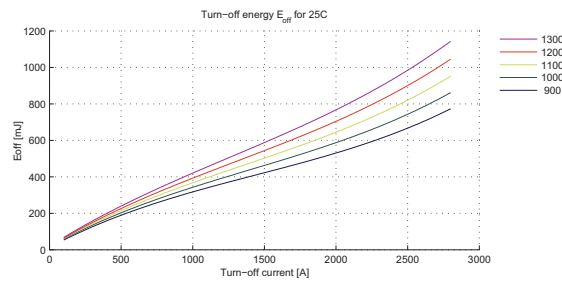


Figure 13: Turn-OFF losses at 25 °C

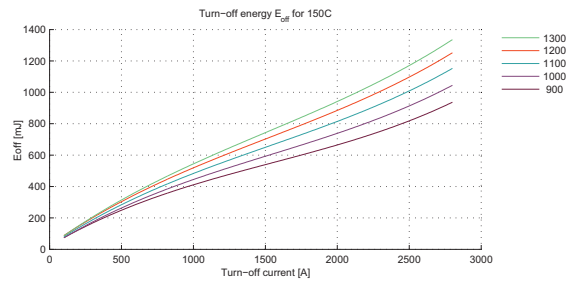


Figure 14: Turn-OFF losses at 150 °C

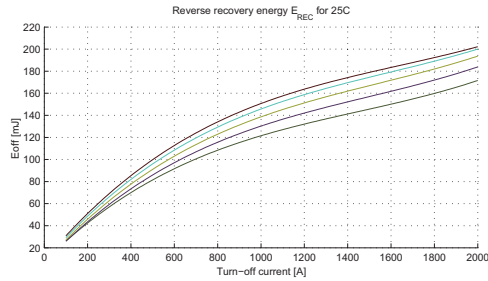


Figure 15: Reverse recovery losses at 25 °C

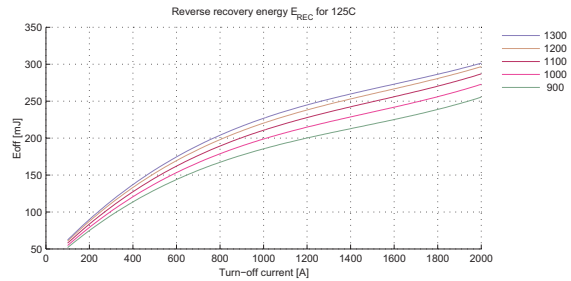


Figure 16: Reverse recovery losses at 125 °C

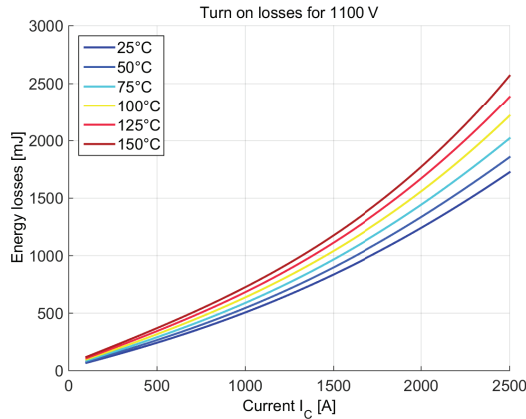


Figure 17: Turn ON losses at 1100 V

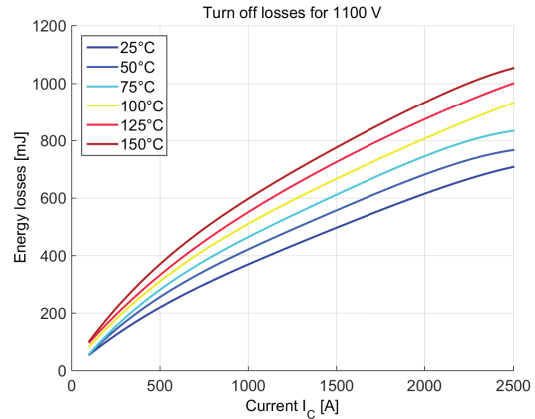


Figure 18: Turn OFF losses at 1100 V

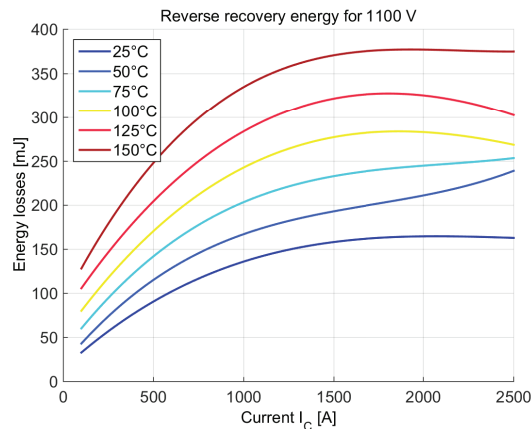


Figure 19: Energy recovery losses at 1100 V

Conclusions

A test platform for full characterization of the power loss in a transistor module was presented. State of the art test systems are dedicated to measure either the conduction or switching losses. The proposed approach can achieve a full characterization of the power loss in the same test platform, without re-configuration. This is achieved by using another auxiliary phase-leg converter, and dedicated measurement systems for switching and conduction losses. To confirm the functionality of the proposed system, a test setup for 1700 V IGBT power modules was realized, and a 1400 A module was characterized. Energy loss variation with temperature, voltage and current was shown for IGBT turn-ON, turn-OFF and diode reverse recovery. Conduction losses were measured for all devices in the test power module and

presented for a transistor and diode. Using such a characterization system can provide realistic data for the power module designers. The time efficiency of a triple pulse tester can enable the test of multiple modules of the same type to enrich the datasheet models and reduce the device junction temperature estimation errors in simulation of power converters.

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