Application Note

Using TPS272C45C High-Side Switch with 60-V Tolerance, Surge, and Inductive Loads

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ABSTRACT

This application note presents a PCB design example using TPS272C45C industrial high-side switch for 60 V tolerance. This report highlights the differences between the 60 V tolerance boards and the standard TPS272C45 evaluation module. The test results for 60 V tolerance, surge test, and inductive load test are also presented in this report.

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1 Introduction

The TPS272C45C is a high-side switch designed for 24-V industrial applications including industrial PLC systems, motor drives, and building automation systems. There is a rising trend for industrial applications, such as safety ultra-low voltage (SELV) systems, to require the high-side switch to withstand up to 60 V. While designing the industrial safety modules, the designers need to account for the failure situations including the fault in the power supply. Because of the use of SELV power supply in such systems, the max voltage during both normal operation and fault events is limited to 60 V. By adding a few components to a system using the TPS272C45C, the device is capable of surviving the 60 V bus voltage in case of a fault event to protect itself and any downstream loads. On the other hand, the higher clamping voltage enabled by the proposed circuit allows for the faster discharge of larger inductive loads while ensuring the safety of the switch. The device also needs to satisfy the industrial safety requirements, including the ability to pass surge standards and inductive load tests. This application note shows the required hardware modifications to the TPS272C45C EVM for 60 V tolerance as well as the test results for the 60 V tolerance, surge, and inductive load driving.

2 PCB Hardware Modifications for 60-V Tolerance

Figure 2-1 shows the schematics for TPS272C45C suited for 60-V tolerance with the modifications to standard EVM highlighted in the red boxes. Figure 2-2 shows a simplified diagram for the schematics with the optional components highlighted in the green boxes. For 60-V tolerance, the C version of the TPS272C45 should be used as it allows the use of an external VDS clamp for higher voltage across the device. There are several 60-V TVS diodes populated on the modified board. D4 between VS and GND absorbs most of the energy when the surge comes in. D10 and D12 both ensure the voltage across the part does not exceed 60 V. Optionally, the TVS and Schottky diode D2 and D8 at the output can be populated to replace D10 for VDS clamping during the inductive load discharge. Do note, other passive components in the circuit such as capacitors also need to be rated above 60 V to survive the high voltage without damage.

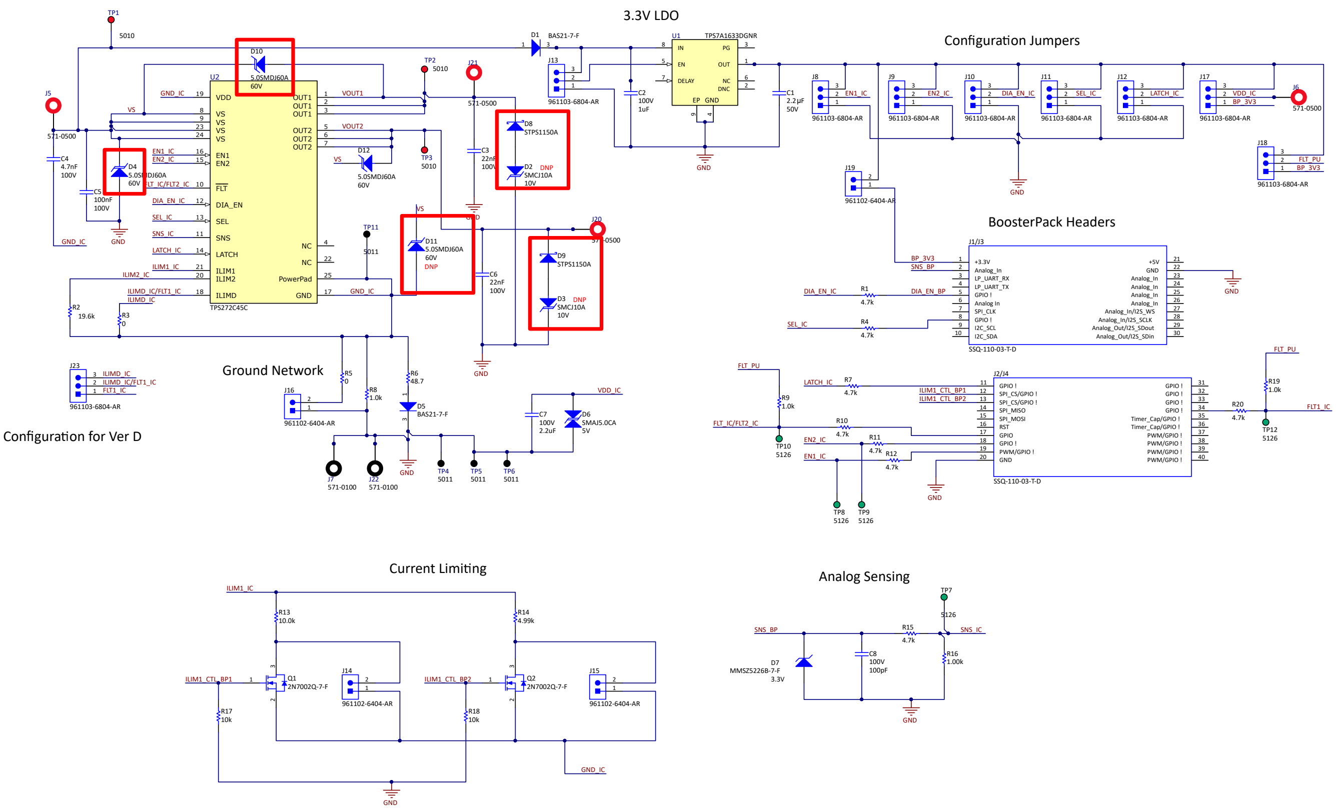

Figure 2-1. TPS272C45C Schematics for 60-V Tolerance

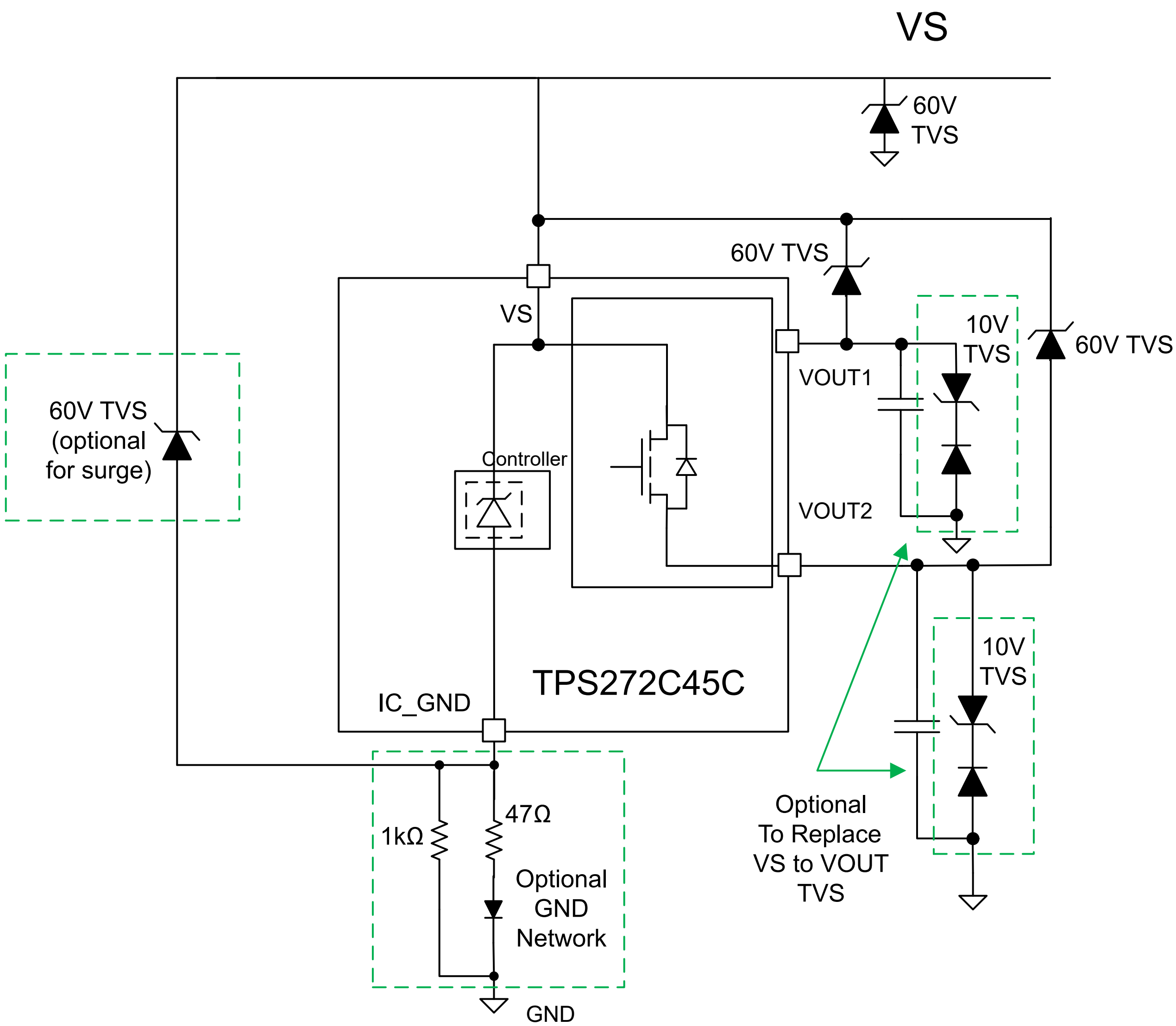

Figure 2-2. Simplified Diagram for the Main Components Needed for 60-V Tolerance

3 60-V Tolerance Test

For SELV systems, the high-side switch can survive and protect itself with a bus voltage up to 60 V in both the ON and OFF states. These two states are tested and examined in the following examples.

The first scenario is when the device is in the ON state and the bus voltage ramps from nominal 24 V to 60 V. In this situation, the over-voltage protection of TPS272C45C will be triggered with the self-protection and fault indication verified in Figure 3-1. As the supply voltage VS is ramping from 24 V to 60 V at 10 V/ms, the FAULT signal is triggered and the FET is shut off automatically below 50 V.

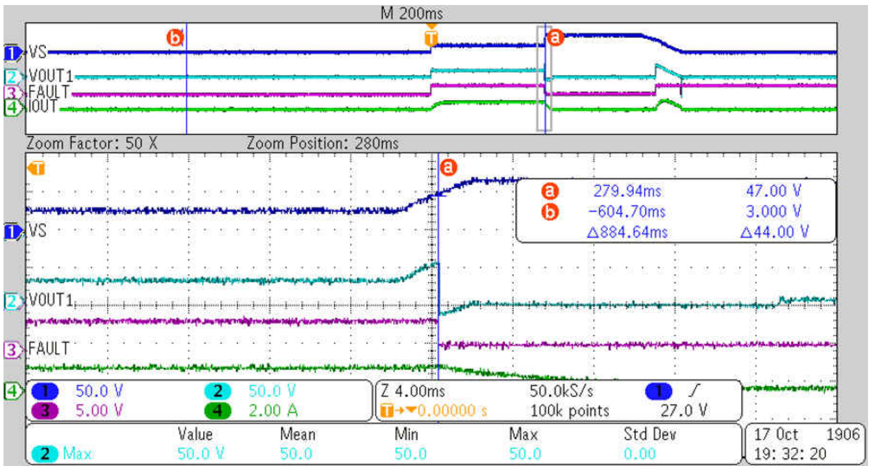

Figure 3-1. Over-Voltage Protection During ON State with Supply Ramping

The second scenario is with 60 V on the input and the device transitioning from OFF to ON state. The FET should remain off in this situation, and the device should not be damaged. Figure 3-2 verifies the operation where the device receives an ON signal while the bus voltage is 60 V. The FAULT signal is triggered when the EN signal goes high while the output of the FET remains off during the entire transient event.

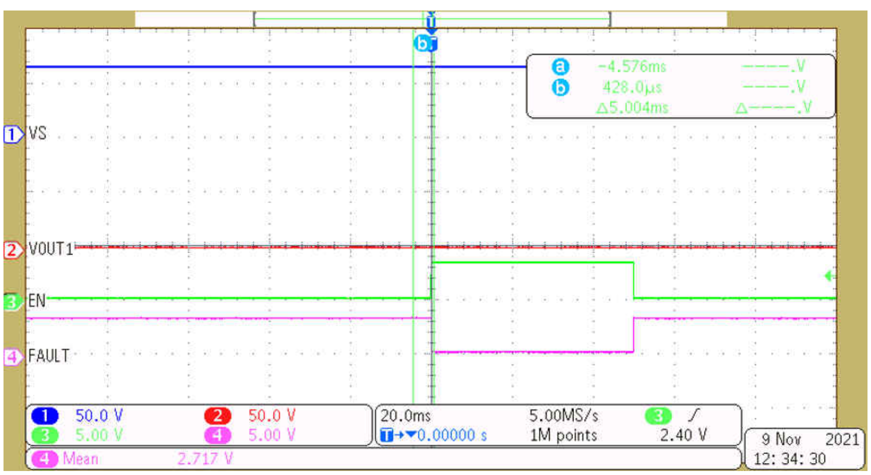

Figure 3-2. Over-Voltage Protection with the Switch Toggling at 60 V

4 Surge Test Results

Surge tests have been performed on TPS272C45C to ensure the robustness of the device. The surge waveform demonstrated in Figure 4-1 follows the IEC61000-4-5 standard at 1 kV with 42 Ω impedance. The 42 Ω impedance represents the impedance between all other lines and GND *IEC 61000-4-x Tests for TI's Protection Devices* application report.

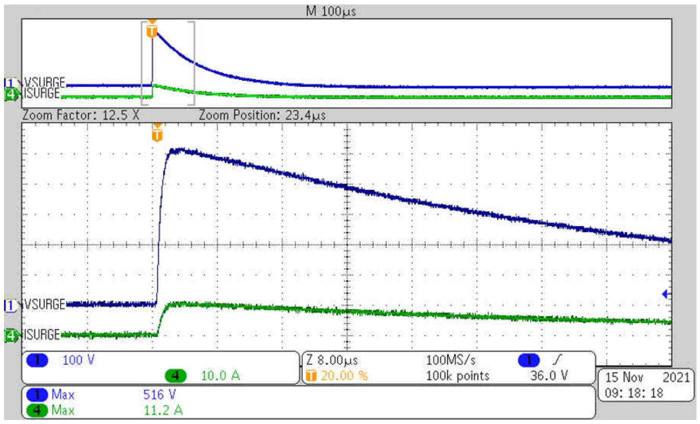

Figure 4-1. Surge Waveform on Resistive Load

Both positive and negative surges have been performed at VS and VOUT, and the two surge test setups are shown in Figure 4-2 and Figure 4-3.

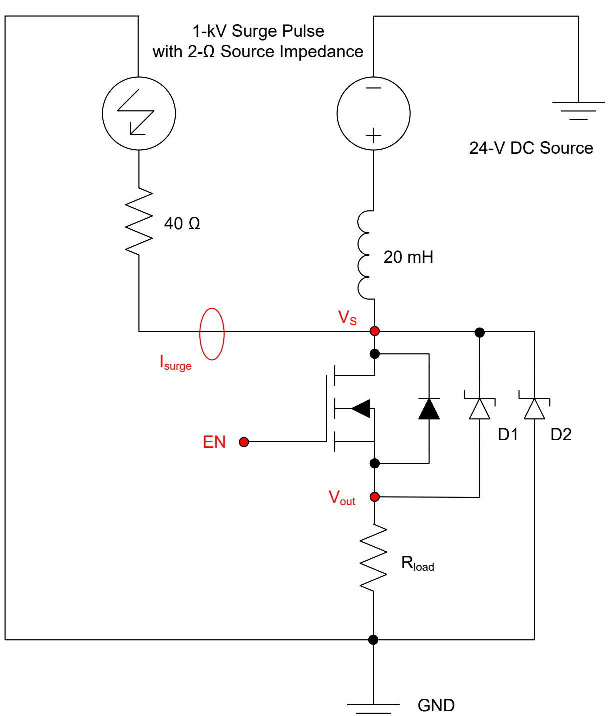

Figure 4-2. Positive Surge Setup

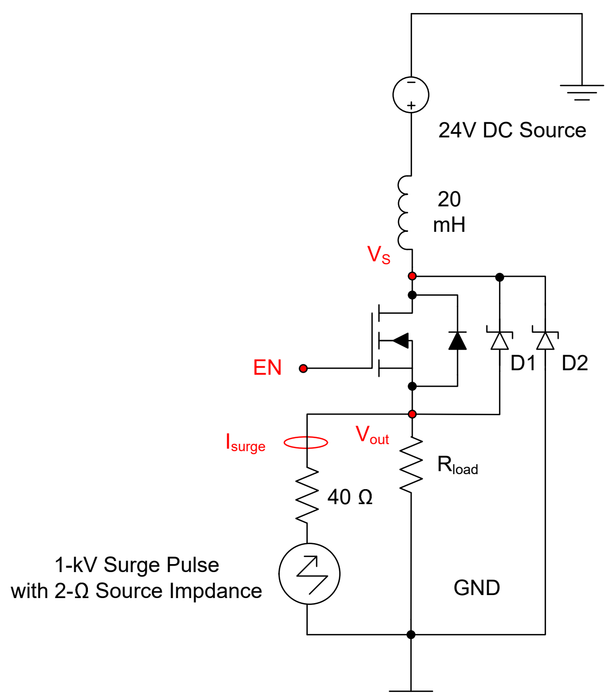

Figure 4-3. Negative Surge Setup

At first, the positive surge is applied on 24-V VS with EN high for both channels and a 12 Ω load connected at the output. The waveform is shown in Figure 4-4. The VS is clamped by the VS to GND TVS diode D2 during the surge event, and it will absorb the majority of the surge energy. The device goes back to the normal operation after the surge.

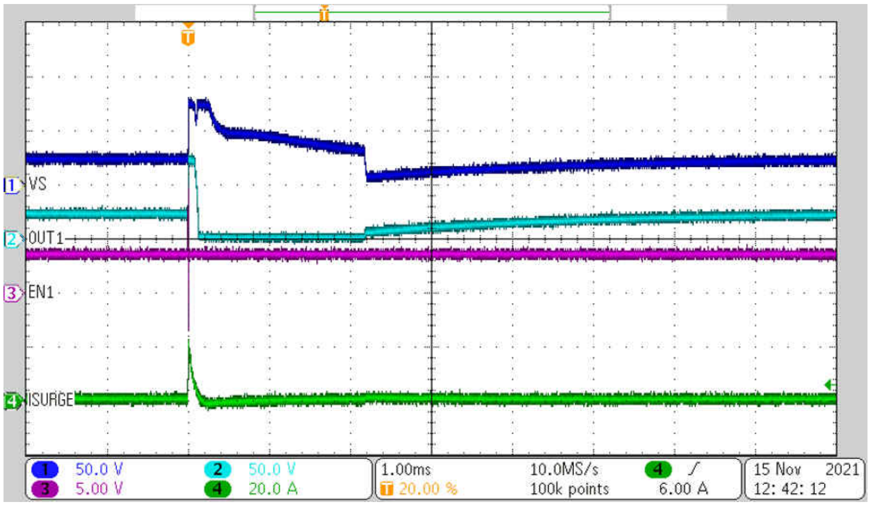

Figure 4-4. Waveform with Positive Surge Applied on VS

The second test involves a negative surge being applied to VS with the same setup. The resulting waveform is shown in Figure 4-5. In this case, the VS to GND diode D2 is conducting and keeping VS at the ground level during the negative surge. The device is operating as expected and kept on after the VS recovers.

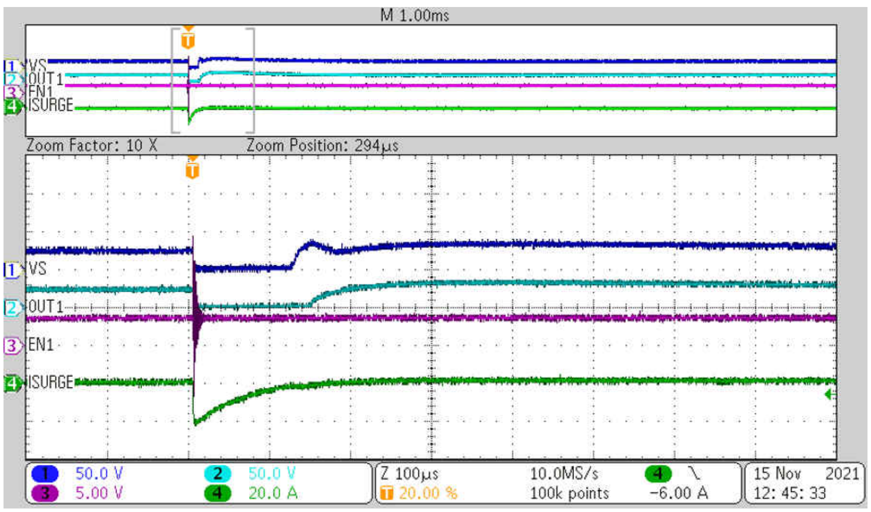

Figure 4-5. Waveform with Negative Surge Applied at VS

Turning now to the test setup demonstrated in Figure 4-3, surges are applied at VOUT with 24 V on the input, EN is high, and 12 Ω is connected to the load. Figure 4-6 shows the resulting waveform when the positive surge is applied. During the surge, the body diode will be conducting, and the diode from VS to GND will clamp the VS voltage. As current keeps flowing in the decoupling inductor, the voltage at Vs will remain high for a short duration and slowly recovers.

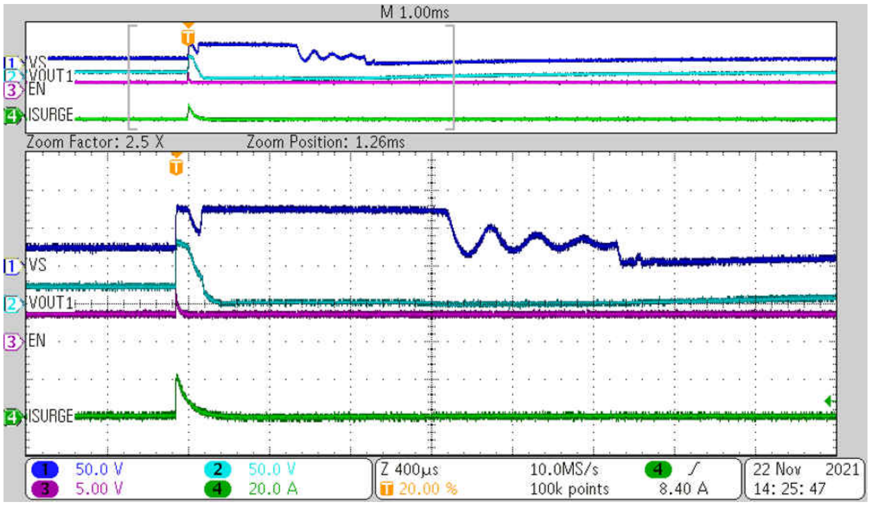

Figure 4-6. Waveform with Positive Surge Applied at VOUT and EN is High

Figure 4-7 shows the resulting waveform when the negative surge is applied to VOUT. The VS to GND TVS diode is conducting, which takes VS to the GND level. The supply and FET operation resumes normal operation after the surge pulse is over.

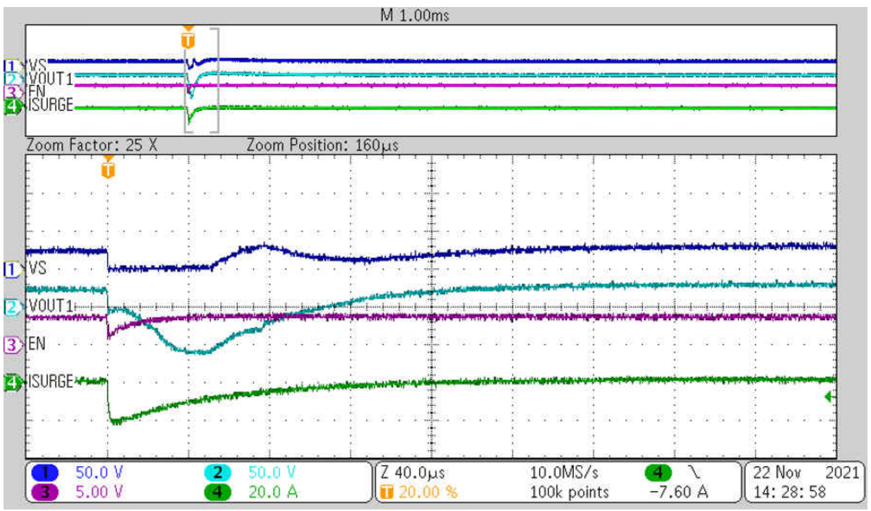

Figure 4-7. Waveform with Negative Surge Applied at VOUT and EN is High

The same surge tests are performed at VOUT while EN is low. With a positive surge at VOUT, Figure 4-8 shows that the TVS diode from VOUT to VS is conducting, and then VS voltage is clamped by the other TVS diode. The device is kept off after the surge event.

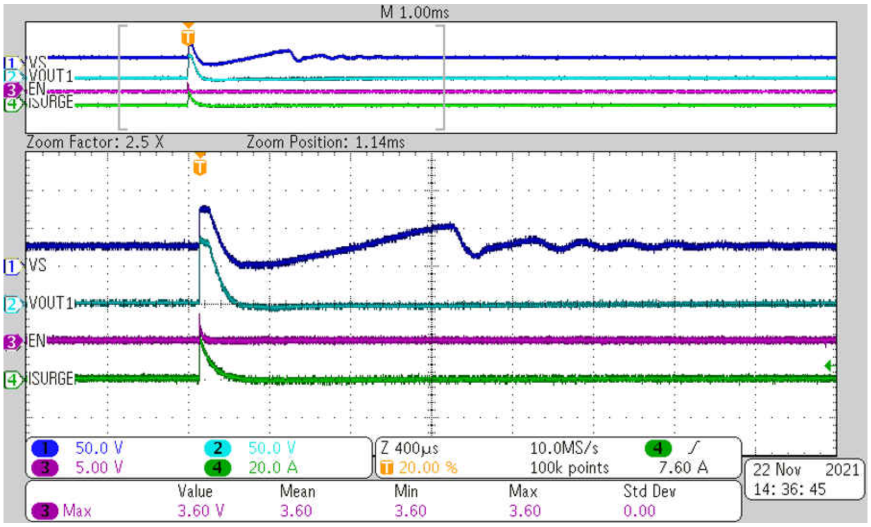

Figure 4-8. Waveform with Positive Surge Applied at VOUT and EN is Low

When the negative surge is applied at VOUT with EN low, Figure 4-9 shows the behavior where the VS to GND diode is conducting and the VS to VOUT diode is clamping. The device remains off after the surge pulse as expected.

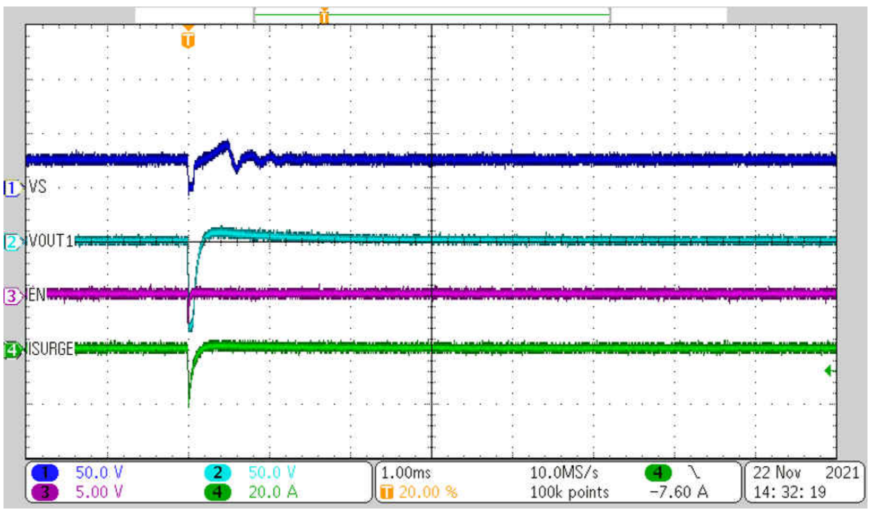

Figure 4-9. Waveform with Negative Surge Applied at VOUT and EN is Low

5 Inductive Load Test

Inductive loads such as relays and solenoids are commonly used in industrial applications *How to Drive Resistive, Inductive, Capacitive, and Lighting Loads* application note. The ability of TPS272C45C to drive an inductive load with repetitive switching is tested in this section. During the turn-off phase of the inductive load, the energy stored in the load will need to be dissipated, and the device needs to survive both the negative voltage at the output as well as the high thermal dissipation due to the repetitive switching.

For the test setup, 24 V is applied at the input with a 1H inductor used as the load. The duty cycle for the input signal is adjusted so the turn-off current is at 500 mA and 2 A. The switching transition for the inductive load is repeated at 1 Hz for 6000 cycles.

The waveform for the switching transition at 500 mA turn-off current is shown in Figure 5-1. The output voltage at the turn-off is clamped by the VS to VOUT TVS diode, which ensures the voltage across the device is under the maximum rating. With the negative voltage at the output, the inductor is discharged quickly, and the output stabilizes to zero afterward. The device operates normally after 6000 cycles of switching.

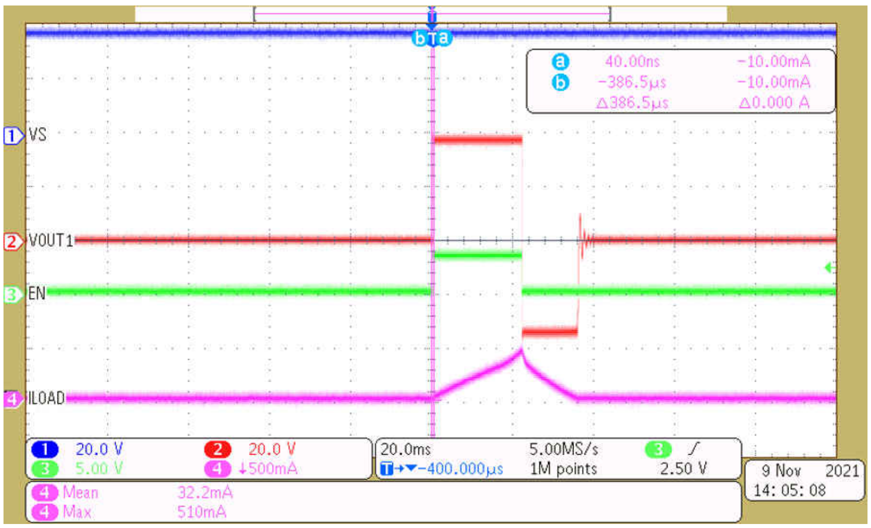

Figure 5-1. Waveform for the Inductive Switching Transition at 500 mA Turn-off Current

Figure 5-2 shows the turn-off current at 2 A with a longer duty cycle. The behavior is similar to the 500 mA case, and the device is operating without issues after 6000 cycles.

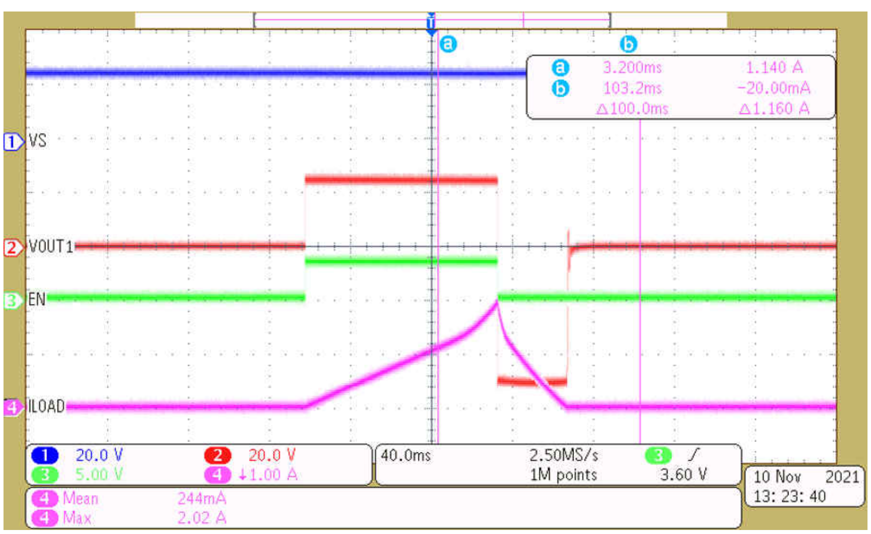

Figure 5-2. Waveform for the Inductive Switching Transition at 2 A Turn-off Current

6 Summary

TI's TPS272C45C high-side switch is designed to be used in industrial applications. In industrial SELV systems, the bus voltage can be up to 60V. While TPS272C45C is designed for nominal 24 V industrial systems, with some modifications to the surrounding circuit, the device can survive 60 V without being damaged. An example of the circuit implementation, as well as the test results, are presented in this report. With the increasing demand for system safety compliance and requirements for 60 V tolerance, the variant of TPS272C45 that doesn't have an internal VDS clamp is still suitable in typical industrial applications and can be protected from different faults cases including surge and 60 V VS.