SIMPLIFIED PRODUCT SAFETY CERTIFICATION THROUGH HARDWARE BASED MOTOR FAULT PROTECTION WITH BRIDGESWITCH™

Household appliances incorporating motors need to comply with specific requirements defined by international safety standards. The integrated half-bridge architecture of BridgeSwitch features a unique low and high-side cycle-by-cycle current limit protection with a failsafe and redundant implementation. This enables it to perform as a protective device protecting the motor during abnormal operation conditions without having to rely on software for controlling the fault condition. Not having to rely on control software for motor protection can significantly simplify and shorten the safety compliance process.

WHITEPAPER

motor drivers

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Introduction

BridgeSwitch is a half-bridge motor driver IC, which incorporates two N-channel power FREDFETs with low and high-side drivers in a low-profile surface mount package. Typical applications include high-voltage single or three phase brushless DC (BLDC) motor drives in domestic appliances such as dishwashers, refrigerators, or fans. Each of the power switches comes with its own cycle-by-cycle current limit protection (refer to [1] for more details). This unique function not only protects the device, but also provides protection for the inverter and the motor during abnormal operation conditions.

Traditionally, fault protection relies on observing the motor by means of monitoring its currents or temperature through sense circuits connected to a microcontroller. Because in this case safe operation of the appliance during a fault condition depends on the microcontroller running control software, international safety standards require compliance certification of the software. This is a time consuming and costly process.

In contrast, hardware based motor fault protection does not rely on a microcontroller executing software. Thus, it simplifies the safety approval process either for an initial product release or for possible subsequent product updates. The following paragraphs provide an overview of applicable safety standards for domestic appliances; explain how hardware based motor fault protection works with BridgeSwitch; and present test results gathered with a reference design.

Safety Standards for Domestic Appliances

The IEC 60335-1 standard “Safety for household appliances and similar electrical appliances” is a commonly applied standard for electrical appliances [2]. It regulates various aspects such as mechanical strength or environmental conditions like moisture or heat. Several electrical safety topics include insulation coordination, overload protection, leakage currents, or over voltage. Clause 19 of the norm addresses how to handle abnormal operation: “Electronic circuits shall be designed and applied so that a fault condition will not render the appliance unsafe with regard to electric shock, fire hazard, mechanical hazard, or dangerous malfunction.” Appliances incorporating inverter driven BDLC motors are subject to additional specific tests as shown in Table 1.

Sub Clause	Abnormal Condition
19.7	Stalled motor
19.8	Disconnected phase (multi-phase motors)
19.9	Running overload
19.11	Faults in electrical circuits

Table 1 Abnormal conditions for inverter driven BLDC motors defined in IEC 60335-1

For the stalled motor test, the rotor is in a locked condition and the appliances operates at rated voltage for a certain period, for example for 5 minutes or until steady conditions are established. The motor winding temperature may not exceed a maximum temperature, which depends on the given winding insulation class (refer to Table 8 in [2] for more details). For example 150 °C after the first hour with Class 105 (A) winding insulation if protected by a protective device.

For appliances with multi-phase motors, one of the phases is disconnected and the appliance operates under normal conditions at rated voltage for a certain period. For example for 5 minutes or until steady conditions are established.

The running overload test starts with the appliance operating under normal operation at rated voltage with steady state conditions established. The load then increases such that the current in the motor winding rises by 10% and the appliances operates until it again reaches steady state. This stepped overload increase repeats until either the protective device interferes or the motor stalls. Motor winding temperature may not exceed a maximum temperature. For example 140 °C for class 105 (A) winding insulation.

Integrated circuits used in inverters have to pass tests that include open circuit at the terminals and short circuit of connected capacitors. For protective electronic circuits, the fault condition is applied to the protective circuit either before the appliance starts up, or at any point in time after the appliance after has started. The goal is to find the most unfavorable condition.

Of particular importance is Annex R “Software evaluation” of IEC 60335-1. It mandates that programmable electronic circuits, which require software to control fault conditions for compliance to IEC 60335-1, have to also meet requirements specified in Annex H of IEC 60730-1 “Automatic electrical controls for household and similar use” [3]. This is usually the case for motor drives where a microcontroller running software provides protection during abnormal motor operation.

Sub clause H.2.22 of IEC 60730-1 defines three distinct classes of control functions as listed in Table 2.

Control Function	Intention
Class A	Not relied upon for the safety of the application
Class B	Prevent unsafe state of the appliance. Failure of control function does not lead directly to a hazardous situation.
Class C	Prevent special hazards such as explosions or whose failure could directly cause a hazard in the appliance.

Table 2 Control function classes defined in Annex H.22.2 of IEC 60730-1

Class B control function is most commonly used in domestic appliances. Since it provides safety during abnormal operation, it has to comply with a host of safety requirements for both, the micro-controller executing the software and the software itself. This includes periodic CPU self-test and component monitoring, for example clock, registers, memory, ADC, I/O periphery and others (refer to Table H.1 in IEC 60730-1 for details [3]).

Annex H.27 of IEC 60730-1 deals with abnormal operation, which includes an assessment against internal faults for electronic circuits in accordance with sub clause H.27.1. Possible failure modes for integrated circuits include open or short circuit faults for capacitors, open circuit at the terminals, and adjacent pin short circuits. Appliances including motor loads are subject to overload (or stalled rotor) tests, where one of the possible failure modes for integrated circuits described above is applied. Passing criteria include no emission of flames, hot metal, or hot plastics and no explosion may occur. Finally, sub clause H.27.1.2 of IEC 60730-1 defines requirements for protection against internal faults to ensure safety. Systems have to be either inherently failsafe or components with direct safety-critical functions are guarded by safeguards. Safeguards have to be hardware based and software may complement them (refer to [3] for details).

Hardware Based Motor Fault Protection with BridgeSwitch

BridgeSwitch is an integrated half-bridge designed to drive high-voltage brushless DC motors. It incorporates two high-voltage N-channel power FREDFETs with low and high-side drivers in a low profile surface mount package.

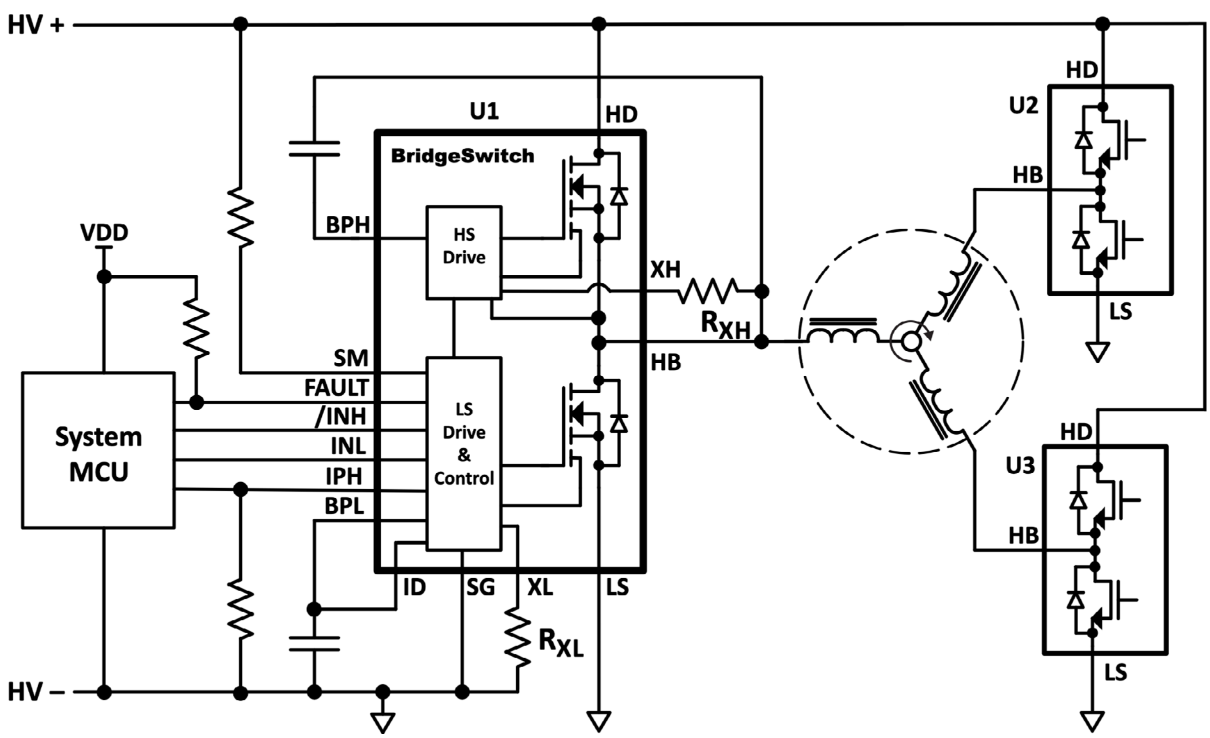


Figure 1 Typical 3-Phase Inverter Motor Drive using BridgeSwitch

Figure 1 depicts the schematic of a typical motor drive employing BridgeSwitch. Three BridgeSwitch devices U1, U2, and U3 form a 3-phase inverter driving the BLDC motor (devices U2 and U3 use simplified schematic symbols). Each of the power switches has a SenseFET output feeding into low or high-side drivers, respectively. This enables implementing a cycle-by-cycle current limit function, which protects the motor during abnormal operation. Resistors R_{XL} and R_{xH} connected at the XL and XH-pins allow setting individually cycle-by-cycle current limit thresholds for the respective FREDFET. As soon as the power FREDFET current exceeds the respective current limit level threshold, the device turns off the power FREDFET. Turning off is very quick and takes only a few hundred nanoseconds from over current detection to initiating turn-off. The device stays off until the respective INL or /INH PWM control inputs receive a turn-off edge followed by a turn-on edge.

BridgeSwitch's current limit protection is inherently failsafe. It constantly monitors current limit selection pins XL and XH. If it detects a short circuit at one of the pins, it disables switching of the respective power switch. If one of the pins becomes open circuit, the respective current limit threshold drops to zero. This effectively prevents any current from flowing in the motor windings during such a fault.

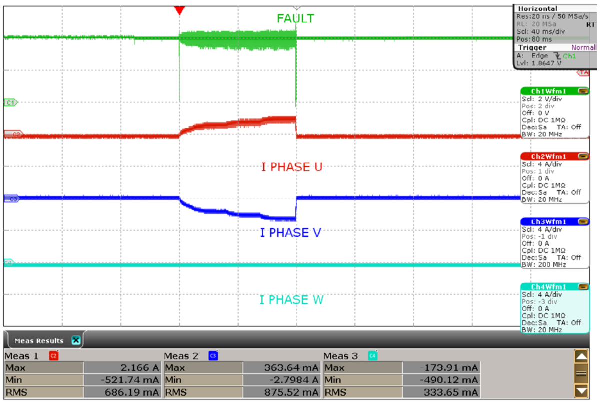
The integrated half-bridge architecture adds an extra level of redundancy to the motor protection. There are always two BridgeSwitch devices in series with the motor, for example devices U1 and U2 in Figure 1. Even if one device would fail, there is a second independent device, which protects the motor during abnormal operation with its own over-current protection function.

BridgeSwitch additionally indicates over-current fault or faults with current limit threshold selection pins to the system micro-controller through the FAULT interface (see [1] for a detailed description). Note that the reporting is independent and no software is involved in protecting the motor.

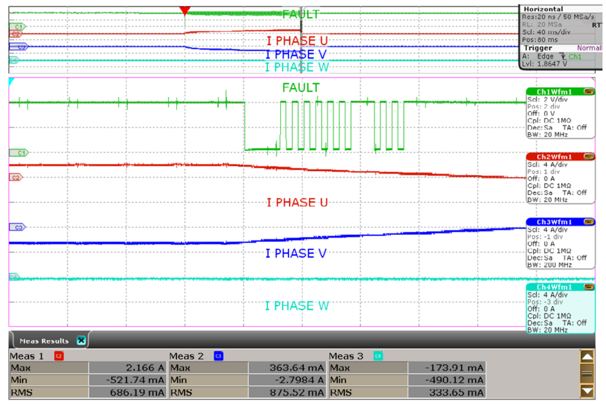
Example Design Test Results

DER-654 is a 300 W 3-phase BridgeSwitch inverter reference design developed by Power Integrations [4]. The inverter features hardware based motor fault protection during abnormal operation conditions specific to appliances with motors listed in Table 1. Tests conducted with this design example apply trapezoidal control with 12 kHz high-side PWM and the inverter operating at 340 V DC bus voltage.

Figure 2 depicts motor winding current waveform plots and the FAULT interface signal of the inverter trying to start up with a locked rotor. Motor phase currents ramp up to 2.9 A when the current limit protection of the BridgeSwitch device driving motor phase V engages and all motor currents drop to zero afterwards. The inverter operates continuously at this particular test condition for 10 minutes during which the motor stays non-operational. There is no device or motor damage during or after the test. The FAULT interface reports the over-current condition to the micro-controller (refer to [1] for details).



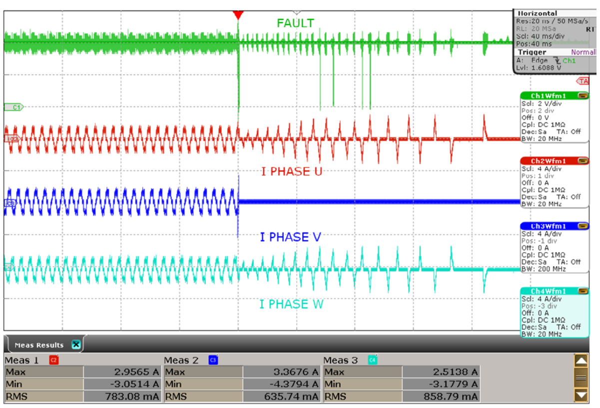
Overview, FAULT interface, phase currents 4 A/Div., 40 ms/Div. timescale



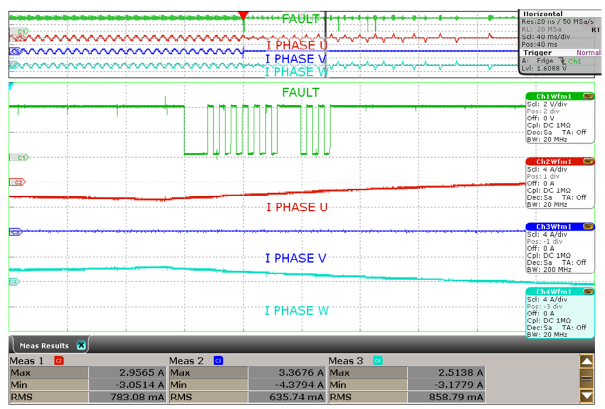
Zoomed view, FAULT interface phase currents 4 A/Div., 0.1 ms/Div. timescale

Figure 2 Motor startup with locked rotor

Figure 3 depicts motor winding current waveform plots and the FAULT interface signal of the inverter during steady state operation with phase V disconnected. The motor continues to operate abnormally until currents for phases U and W reach current limit thresholds of respective devices and then stalls. BridgeSwitch flags the over current faults to the micro-controller through the FAULT interface.



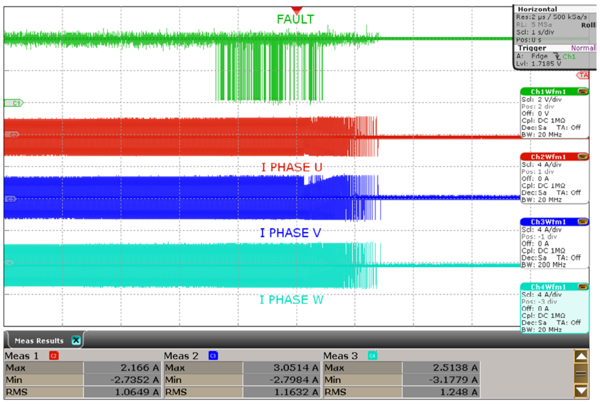
Overview, FAULT interface, phase currents 4 A/Div., 40 ms/Div. timescale



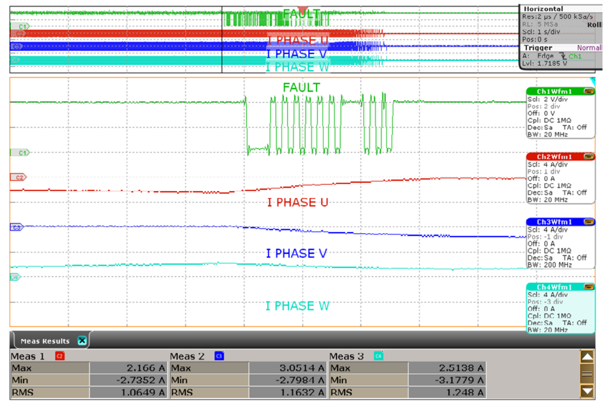
Zoomed view, FAULT interface phase currents 4 A/Div., 0.1 ms/Div. timescale

Figure 3 Disconnected phase test

Figure 4 depicts motor winding current waveform plots and the FAULT interface signal during a running overload test. At the beginning of the test, the inverter delivers the default output power of 300 W in steady state. The motor load then increases until the current in the motor winding rises by 10% and the inverter operates until it again reaches steady state. This stepped overload increase repeats until the motor winding current reaches the set current limit threshold of the device. In this example, over current triggers for all three devices and each device indicates the fault to the micro-controller through the FAULT interface. The motor eventually stops with no device or motor damage after 10 minutes operation under this condition.



Overview, FAULT interface, phase currents 4 A/Div., 1 s/Div. timescale



Zoomed view, FAULT interface phase currents 4 A/Div., 0.1 ms/Div. timescale

Figure 4 Running overload test

UL Informative Report

UL reviewed test results gathered with example inverter design DER-654 [4] during abnormal motor operation and concluded, that it is compliant to abnormal motor operation requirements of IEC 6033-51 listed in Table 1 and to IEC 60730-1 sub clause H.27.1 without relying on software to control these fault conditions. UL Informative Report no. 4788685352 documents results of the conducted review and is available for download from Power Integrations' website [5]. The informative report consists of five parts in total; the main report and four attachments:

- Test Report IEC 60335-1
- Attachment 1: Photographs
- Attachment 2: Engineering Report DER-654 with Test Results
- Attachment 3: AN-76 Device Level Single Fault Test Results
- Attachment 4: Test Report IEC 60730-1

Application note AN-76 documents test results of device level single faults in accordance to sub clause 19.11 of IEC 60335-1 and to sub clause H.27.1.1.5 of IEC 60730-1 9 (where applicable). This includes open circuit at all pins, adjacent pin short circuit, low-side logic pin short circuit to device system ground, and high-side logic pin short circuit to half-bridge connection.

Conclusion

BridgeSwitch's fail safe low and high-side cycle-by-cycle current limit function protects the inverter and the motor during abnormal operation conditions. With the integrated half-bridge architecture, there are always two independent devices in series with the motor providing additional redundancy. Motor protection during abnormal operation is hardware based and does not rely on software. BridgeSwitch's hardware based motor fault protection therefore enables a significant simplification of the safety certification process for household appliances with the possible use of a Class A control function.

References

[1] "BridgeSwitch Family Datasheet", Power Integrations, Inc., October 2019

[2] IEC 60335-1 Ed. 5.2, Safety for household appliances and similar electrical appliances, IEC, May 2016

[3] IEC 60730-1 Ed. 5.1, Automatic electrical controls for household and similar use, December 2015

[4] "DER-654 300 W 3-phase Inverter Using BridgeSwitch", Power Integrations, May 2019

[5] "Informative Test Report 4788685352", UL LLC, December 2018

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