Application Brief

Safe Torque Off Systems Using TPLD

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Safe Torque Off (STO) is one of the most fundamental and widely used functional-safety features in modern motor drives, servo amplifiers, and robotic power stages. Defined primarily in **IEC 61800-5-2** (Adjustable speed electrical power drive systems – Safety requirements – Functional), STO verifies that the *drive is reliably torque-free* by preventing any torque-producing power from reaching the motor. The function maps directly to stop category 0 (EN 60204-1) and is a core requirement for compliance with **IEC 61508** SIL 3, **ISO 13849-1** Performance Level e (PL e) / Category 3–4, and robotics-specific standards such as **ISO 10218-1/2**. As noted in the application brief *Design Smaller STO Systems Using Integrated 3-Phase Smart Gate Drivers*, the size of the STO circuit is constrained by the size of the motor system hardware, and is trending towards a smaller overall design size. Modern motor drive systems implement STO with diagnostic functions using discrete logic gates, timer circuitry, comparators, and low-pass filter components, all of which can be integrated into a single TI Programmable Logic Device (TPLD).

Simplified TPLD Safe Torque Off Circuitry for Motor Drive System

Gate drivers in motor drive systems are deliberately supplied with a VCC (typically VM for devices such as the DRV8350F) that is as close as possible to the recommended V_{GS} of the FETs being driven to minimize $R_{DS(on)}$ and keep conduction losses as low as possible. However, power FETs, especially Si or SiC MOSFETs, have very tight maximum V_{GS} ratings; as a result, any overvoltage on the VCC rail of the driver can violate this rating on the gate voltage, causing immediate damage. The primary goal of an STO circuit as shown in Figure 1 is to disconnect the gate-driver supply voltage (VM) as soon as an STO command or detected fault (including supply-rail anomalies) occurs, thereby protecting the FETs from damage and preventing torque generation.

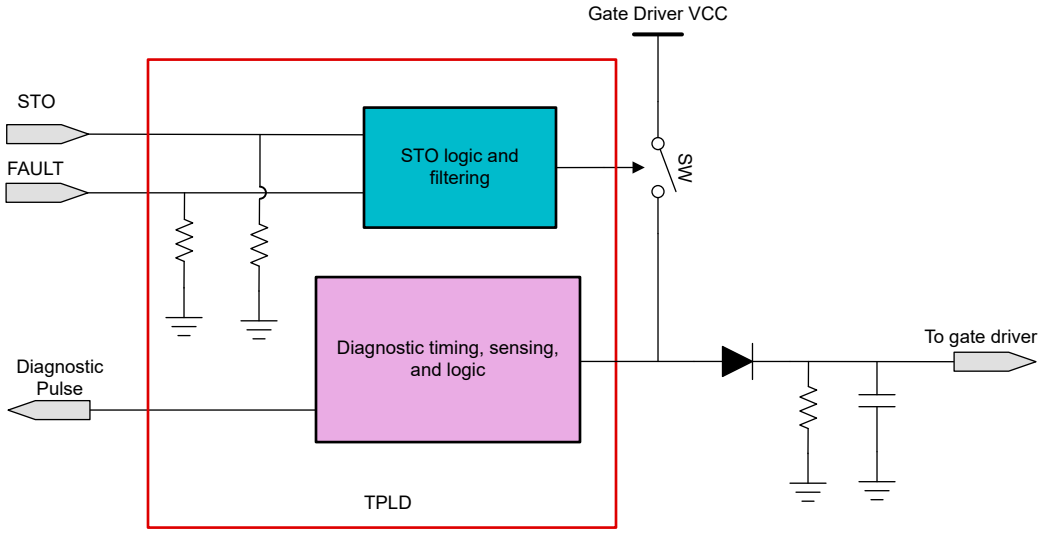

Figure 1. Block Diagram of a Typical Safe Torque Off Circuit

The circuit in Figure 1 accepts two key inputs: STO (one of the dual-channel STO signals, typically provided as isolated 3.3V logic from 24V safety inputs) and FAULT (fault feedback from the gate driver). These are routed to the TPLD, which integrates all of the discrete logic, timing, analog comparison, and monitoring elements typically used in STO circuitry into a single programmable device. The signals are filtered and processed by the TPLD's on-chip logic; if either signal falls low, the TPLD opens the load switch and the gate-driver supply is disconnected.

The circuit also incorporates additional logic and timing elements for periodic diagnostic testing as highlighted in the purple box. TPLD integrated comparators, logic, and timing elements (such as pulse generators and watchdog timers) can be used to force the load switch to open briefly and monitor whether or not the switch opens. Motor interruption is not interrupted during the test, as the downstream capacitor provides hold-up. If the switch fails to open or another problem is detected according to the logic inside the TPLD, the integrated watchdog times out and asserts a diagnostic failure, triggering a safe-state shutdown. This continuous online self-test delivers the high diagnostic coverage (DC ≥ 90%) required for SIL 3 (IEC 61508) and PL e (ISO 13849-1) while enabling non-destructive periodic proof testing.

TPLD devices can also provide active control over PWM signals provided to the gate drivers. Each PWM signal can be routed and buffered through the TPLD, whose outputs can be configured to be high impedance or forced low when the STO signal is active, verifying the gate drivers receive no switching commands during the safe state.

Conclusion

TPLD-based STO implementations deliver a compact, single-device design that integrates gate-driver supply cutoff, continuous 100Hz diagnostic pulsing, rail monitoring, watchdog timing, and optional PWM disable. By replacing the multi-IC discrete logic and external MCU required in traditional designs (for example, TIDA-01599), these circuits reduce board area and BOM cost by 50–70% while providing true hardware-only, deterministic diagnostics. The resulting high diagnostic coverage and non-destructive proof-test capability directly satisfy the most stringent functional-safety requirements of IEC 61800-5-2, IEC 61508 SIL 3, ISO 13849-1 PL e / Cat. 3–4, and robotics standard ISO 10218-1. Designers of industrial drives, servos, and collaborative robots can therefore achieve certified safe-torque-free operation with smaller footprints, lower certification effort, and maintained high efficiency.

Learn more about TPLD with the Engineer's guide to programmable logic.

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