Technical Article

Taking e-bike safety to the next gear with active short circuit technology

TEXAS INSTRUMENTS

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Battery-powered e-bikes and e-scooters offer a sustainable and environmentally friendly alternative to traditional motorcycles. Many e-bikes use a larger 48V or 36V battery to provide adequate torque while allowing for lower current. But with the growing demand for high-powered e-bikes, designers and manufacturers face significant design challenges to help ensure safety and reliability.

The fundamental architecture in an e-mobility system is the low-voltage traction inverter motor that aids in pedaling during normal riding and reduces rider effort when biking uphill. An electric motor, usually located on the wheel, converts electrical energy into mechanical energy or generates electrical energy from mechanical energy. The latter can occur in a controlled (regenerative braking) or an uncontrolled manner.

When the motor spins without being controlled (coasting), the back-electromotive force supplies current back to the battery through the diode rectification of the power stage. This coasting state can present challenges associated with unstable increases in the battery voltage. A supply-pumping state, also known as generator-mode operation, can occur someone pushes the bike, it rolls downhill, or the rider pedals when the battery is not connected or the controller is not awake to monitor the supply voltage. If not controlled, the supply voltage can increase beyond the electrical system’s operating limits, resulting in potential damage to the circuit from an electrical overvoltage event. System designers must determine how to control the system’s energy before it crosses the operating limit.

Active short circuit technology

Active short circuit is an engineering technique that safely dissipates large amounts of energy. It implements a braking feature that turns on all high- or low-side metal-oxide semiconductor field-effect transistors (MOSFETs), which shorts the motor and creates a path to recirculate high current through the MOSFETs instead of flowing to the supply.

Figure 1 shows an e-bike system architecture using TI's DVR8363-Q1 gate driver that implements brake mode using the ASCIN pin.

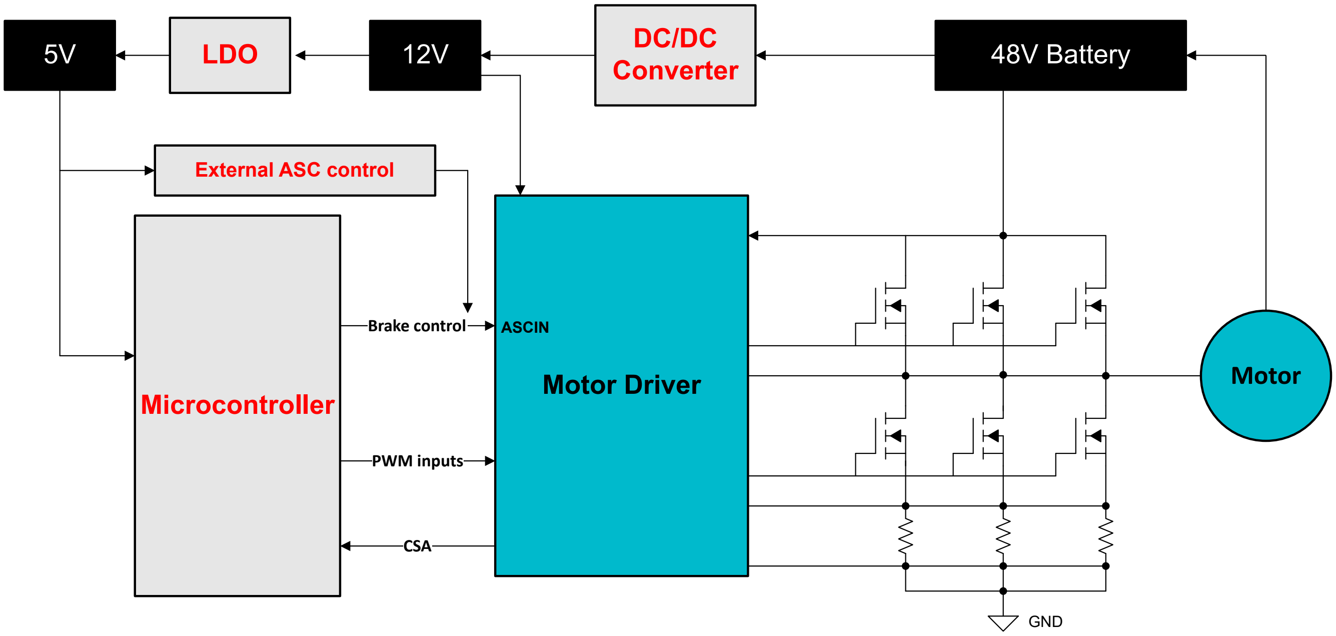

Figure 1. E-bike system block diagram showing the DRV8363-Q1 with brake control

While early e-bike manufacturers used discrete components to measure the battery voltage and trigger brake mode if that voltage crossed the allowable threshold, external systems can't react dynamically to MOSFET failures. For example, if a system fault indicated damage to the high-side MOSFET, you would want to use high-side braking instead of low-side braking to avoid shorting the supply to ground.

In newer designs, the DRV8363-Q1 addresses braking challenges while reducing board space through feature integrations. The logic-level ASCIN pin can trigger emergency brake mode in the event of system faults. The DRV8363-Q1 can also trigger active short circuit over Serial Peripheral Interface (SPI) or automatically during an overvoltage condition. This gate driver is configurable to trigger either low- or high-side braking based on the register setting.

I see six primary adverse conditions in an e-bike brake implementation:

- **A shoot-through condition when using low-side braking in the event of a high-side MOSFET short (or vice versa).** If the high-side MOSFET becomes damaged during operation, and if the system triggers active short circuit mode for the low side, there will be a path from the 48V supply to ground, causing a high-current shoot-through event that may damage the system and pose risks to users.

  The advanced protection features of the DRV8363-Q1 shown in Figure 2 include built-in logic to detect a high-side MOSFET short condition through drain-to-source voltage monitoring, followed by overriding the low-side active short circuit command to switch to high-side braking, which safely dissipates current while preventing a short to ground. These protection logic and diagnostic features improve user safety and reduce firmware resource demands.

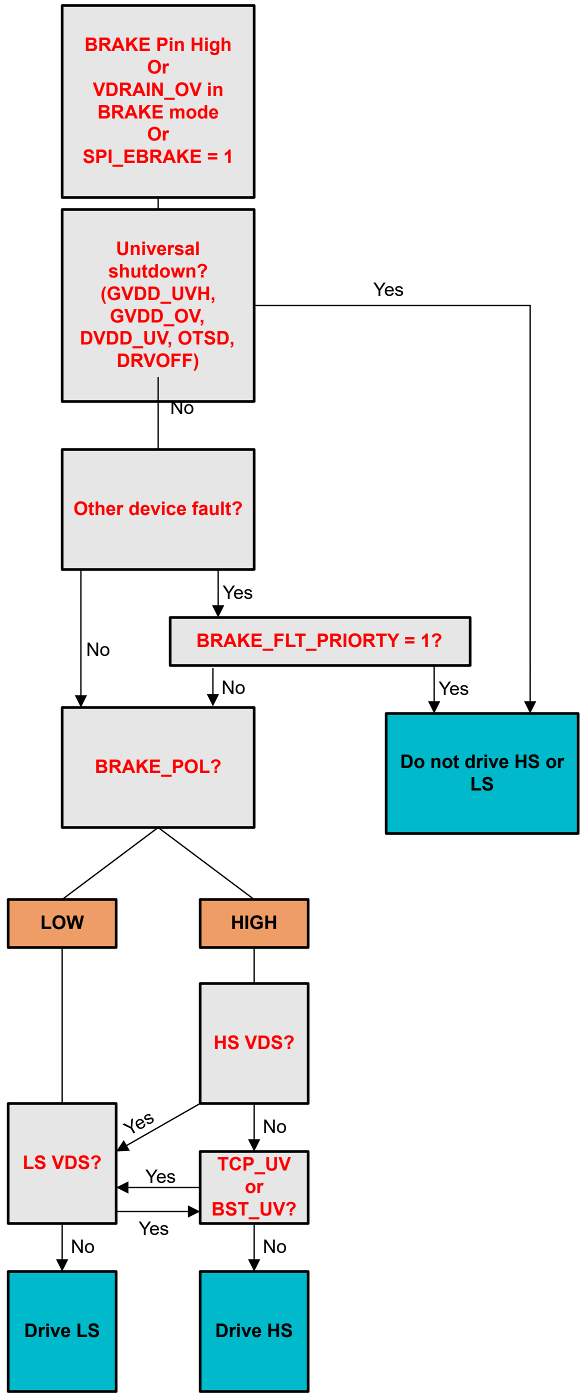

Figure 2. Smart logic in active short circuit to prevent shoot-through

- **High-current spikes on motor phases when switching between brake mode and freewheeling mode.** When a user coasts downhill, the free-spinning motor will cause the battery voltage to rise. In a discrete brake-mode system, the braking will trigger when the voltage crosses a certain limit, reducing the voltage. However, once the voltage drops below the threshold, braking will stop and the free-spinning motor will cause the battery voltage to rise again. This can work for low-current scenarios but can be dangerous in high-current applications, where the transition between braking and freewheeling will cause current spikes that may damage onboard components.

  The DRV8363-Q1 offers an advanced response to control rising voltages, enabling designers to program either a retry or latched brake-mode based on the system requirement.

- **MOSFET thermal damage during braking.** In high-current brake scenarios, using either low- or high-side braking exclusively will result in MOSFET heating, as MOSFETs conduct continuously while current is dissipating. Figure 3 shows the current flow direction between the two brake modes.

  With the ability to trigger low- or high-side braking over SPI, the DRV8363-Q1 can toggle between high- and low-side active short circuit to help distribute heating and better manage board thermals.

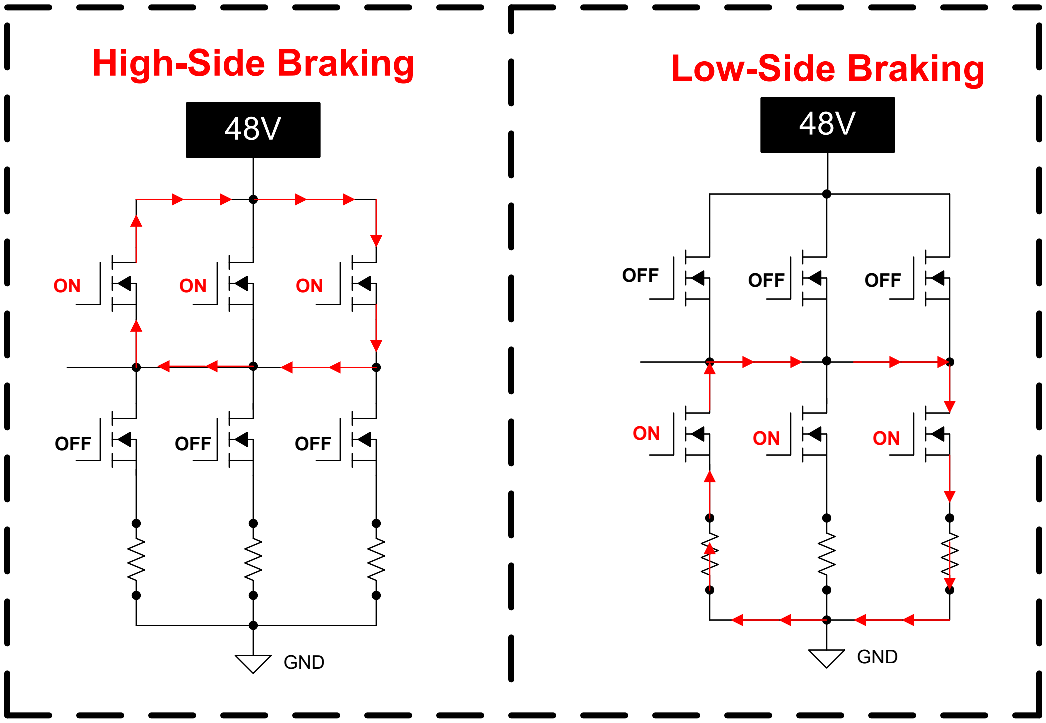

Figure 3. Active short circuit implementation: high side vs. low side

- **Inaccurate supply-voltage measurement and slower response times.** Discrete braking implementations often suffer from the inaccuracy of the sensed voltage at the battery versus the one measured at the MOSFET drain. Furthermore, the sampling and decoding of the data by the microcontroller (MCU) commanding the brake signal can delay the system's response time, which can be dangerous in emergencies.

  By measuring the battery voltage at the high-side MOSFET drain directly, the DRV8363-Q1's integrated active short circuit system improves accuracy and response time in triggering brake mode during overvoltage events.
- **An inability to trigger active short circuit if the MCU is damaged or a driver fault state exists.** While MCU-controlled pulse-width modulation signals can manually enter a braking state, the integrated active short circuit function in the DRV8363-Q1 offers a more reliable braking method, even during hardware fault conditions. For example, if a code execution error or internal hardware fault interrupts the MCU, the DRV8363-Q1 can automatically activate active short circuit in response to supply overvoltage conditions without an external MCU-commanded trigger. In case of a failure inside the DRV8363-Q1, active short circuit can bypass certain internal faults, overriding shutdown to enforce braking.
- **Increased board space and bill-of-materials (BOM) costs.** Implementing a discrete active short circuit solution involves multiple comparators and sensing circuitry, thus increasing BOM costs for the final solution and taking up board space, which is a concern in e-bike applications with strict space and weight requirements.

Conclusion

TI's DRV8363-Q1 addresses specific safety concerns in e-mobility systems through active short circuit technology for braking and MOSFET monitoring capabilities. To enhance e-bike safety, the device offers programmable control features that help prevent potentially dangerous voltage spikes and maintains reliable performance in motor and generator modes.

Additional resources

Check out the *DRV8363-Q1 48V Battery Three-Phase Smart Gate Driver with Accurate Current Sensing and Advanced Monitoring Data Sheet* and the DRV8363-Q1EVM evaluation module.

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